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PREPARED UNDER THE DIRECTION OF THE MINERAL RESOURCES COMMITTEE OF THE IMPERIAL INSTITUTE, WITH THE ASSISTANCE OF THE SCIENTIFIC AND TECHNICAL STAFF

COAL

BY J. H. RONALDSON, M.I.M.E., M.Inst.M.M., F.G.S.

WITH 12 MAPS AND 2 DIAGRAMS

LONDON
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PREFACE

THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin of the Imperial Institute* during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilisation of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

IMPERIAL INSTITUTE,
LONDON, S.W.7,
Sept. 1929.

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BRITISH SOURCES OF COAL SUPPLY

NOTE:—*Numerals in square brackets in the text refer to the Bibliography at the end.*

COAL

CHAPTER I

COAL: HISTORY, GROWTH AND OUTPUT OF THE COAL INDUSTRY

HISTORICAL

IT may be regarded as remarkable that the use of coal has only become general within the last few centuries, though the existence and the combustible character of coal must have been known in very early times. It is believed that it was used as a fuel by the Chinese long before the Christian era, and evidence of its use by the Romans, during their occupation of Britain, exists in the coal and ashes found among the ruins of many of their stations near the coal-fields [4/p. 5].

W. Warington Smyth states that "the first worked coal-field in Germany seems to have been Zwickau, in Saxony, dating from about the tenth century" [8/p. 3]. Certain ecclesiastical records indicate that coal was being won prior to A.D. 1113 in the coalfield of Worm, which lies partly in the districts of Julich, Aschen and Limburg [1] [3] [7]. There is no clear evidence that elsewhere coal was mined to any extent till toward the end of the twelfth or the beginning of the thirteenth century. About this time Cistercian monks are said to have mined coal from the outcrops of seams in the high ground of a suburb of Liége, and R. L. Galloway [4] says, "Its discovery in Belgium, according to the legend as quoted by Schook in his

Tractatus de Turfis (Gronigæ, 1658, p. 223), was made in 1189 by a pilgrim, who pointed it out to a smith." About the same time, according to Galloway [5], the monks of Holyrood Abbey received a grant of the tithe of the colliery of Carriden, near Blackness, west of Edinburgh, and the monks of Newbattle Abbey, near Dalkeith, received a grant of a colliery on the seashore at Preston, east of Edinburgh.

Galloway further says that in England, soon after the granting of the Magna Charta (A.D. 1215), there is "evidence of a commencement having been made to work coal and to carry it from the north of London," that "before the close of the reign of Edward I (A.D. 1307) the mineral was being dug, though doubtless only on a small scale, in most of the coal-fields of England, Wales and Scotland," and that at first it was "only used by humble artisans, such as smiths and limeburners." But at this time its use in London met with such opposition on account of the smoke that an enactment was passed forbidding its use under severe pains and penalties. However, in spite of this, and doubtless on account of the growing scarcity of wood, its use increased and was extended to domestic purposes.

Gradually the demand for coal also arose in France, and, by the end of the sixteenth century, the export of coal to that country appears to have attained relative importance,[1] so much so, indeed, that the fear of exhausting the supply raised the question of prohibiting its export from England. No definite action, however, was taken, but in Scotland "an Act of Parliament was passed in 1563 prohibiting all persons from transporting coals out of the realm under penalty of confiscation of the ship and cargo."

The introduction about this time of the process of making cast iron, for which purpose wood charcoal was used, followed by a great demand for large cast-iron cannon, hastened the exhaustion of wood fuel in England and fostered the use of coal. It is, however, to the invention and perfecting of the modern steam engine, the conversion of coal into coke, and improvements in the metallurgy of iron, at a later date, that is chiefly due the phenomenal increase in the consumption of coal.

[1] France continues to be the chief importer of British coal, and in 1913 took 12¼ million tons [6].

during the last century, an increase evidenced by the following figures [8/p. 9].

It is estimated that about the year 1800 in Great Britain about 10,000,000 tons of coal were raised in a year; that in 1850 the production was 42,000,000 tons, that France was raising 4,433,000 tons, Prussia and Belgium smaller quantities, and Austria a little above 1,000,000 tons. A comparison of these figures with those on page 5, and the diagrams on pages 8 and 9, give a striking illustration of the rapid growth of coal-mining to its present enormous proportions, of the progressive character of the industry, and of the world-wide competition.

Classification of Coals

The classification of coals adopted in *The Coal Resources of the World*, 1913, is as under:

Anthracite.— Class A_1.
- Fuel ratio,[1] 12 or over.
- Calorific value, 14,500 to 15,000 B.T.U.
- Carbon, 93 to 95 per cent.
- Volatile combustible matter, 3 to 5 per cent.

Semi-anthracite.— Class A_2.
- Fuel ratio, 7 to 12.
- Calorific value, 15,000 to 15,000 B.T.U.
- Carbon, 90 to 93 per cent.
- Volatile, 7 to 12 per cent.

Anthracitic and High-carbon Bituminous.—Class B_1.
- Fuel ratio, 4 to 7.
- Calorific value, 15,200 to 16,000 B.T.U.
- Carbon, 80 to 90 per cent.
- Volatile, 12 to 15 per cent.
- Does not readily coke.

Bituminous.—Class B_2.
- Fuel ratio, 1·2 to 7.
- Calorific value, 14,000 to 16,000 B.T.U.
- Carbon, 75 to 90 per cent.
- Volatile, 12 to 26 per cent.
- Generally cokes.

[1] The fuel ratio is obtained by dividing the percentage of fixed carbon by the percentage of volatile matter.

Low-carbon Bituminous.—Class B_4.

Moisture content occasionally reaches 6 per cent.

Volatile matter, up to 35 per cent.

$$\frac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile}}{\text{Hygroscopic moisture} + \frac{1}{2}\text{ volatile}} = 2{\cdot}5 \text{ to } 3{\cdot}3.$$

Calorific value, 12,000 to 14,000 B.T.U.

Carbon, 70 to 80 per cent.

Makes porous, tender coke.

Cannel.—Class C.

Yields 30 to 40 per cent. volatile matter on distillation.

Calorific value, 12,000 to 16,000 B.T.U.

Very porous coke.

Lignitic or Sub-bituminous.—Class D_1.

Generally contains over 6 per cent. of moisture.

Moisture, freshly mined, up to 20 per cent.

$$\frac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile}}{\text{Hygroscopic moisture} + \frac{1}{2}\text{ volatile}} = 1{\cdot}8 \text{ to } 2{\cdot}5.$$

Calorific value, 10,000 to 13,000 B.T.U.

Carbon, 60 to 75 per cent.

Lignite.—Class D_2.

Moisture in commercial output, over 20 per cent.

Calorific value, 7,000 to 11,000 B.T.U.

Carbon, 45 to 65 per cent.

See also Appendix, p. 159.

Production, Consumption, Exports, Imports and Reserves of Coal

In order to realize the magnitude and resources of the coal industry, it will be useful, before referring in detail to the coal-fields of the British Empire, to include tables giving:

TABLE I

Table of the Annual Coal Production of the Principal Countries of the World

In million tons (metric tons of 2,204 lb.) *

	1895.	1905.	1913.[a]	1916.	1917.[c]	1918.[c]	1919.[b]
British Empire:							
Great Britain and Ireland	194·35	239·89	292·12	260·562	252·50	231·36	233·48
Australia	4·01	6·83	12·02	9·972	10·07	11·13	10·70
Canada	3·19	7·96	13·62	12·718	12·75	13·59	12·38
India	2·65	7·92	16·07	17·536	18·51	21·05	22·11
New Zealand	0·76	1·41	1·92	2·294	2·10	2·07	—
South Africa	1·40	3·22	7·99	9·081	7·07	9·40	9·85
Total	206·36	267·23	344·34	312·16	305·06[d]	288·60	—
Other Countries:							
Austria-Hungary	27·25	40·72	53·68[d]	46·099	—	—	—
Belgium	20·41	21·84	22·84	18·863	14·92	13·82	18·49
China	—	—	9·27[e]	—	—	—	—
France	28·24	36·05	40·84	21·473	28·90	24·14	22·34
Germany	103·96	173·66	278·03[d]	158·89	167·36	160·51	210·30
Italy	0·25	0·31	0·37	1·306	1·72	2·00	—
Japan	4·84	11·89	21·42	22·902	26·52	23·74	30·83
Mexico	—	2·45	—	—	—	—	0·45
Russia	9·10	17·12	33·37	26·282	—	—	—
Spain	1·77	3·20	4·02	5·495	5·68	7·16	—
Sweden	0·20	0·33	0·36	0·41	0·44	—	—
United States	177·59	351·12	517·20	535·479	591·11	615·43	493·75
Other Countries	1·75	4·55	14·66	113·64	195·34	196·60	105·31
Grand Total (approx.)	581·72	928·02	1,341·0[f]	1,263·0[g]	1,339·0	1,332·0	1,170·0

[a] Figures for 1913 and 1916 are taken from official returns. Supplemented by figures from statistics of Iron and Steel Federation.
[b] N.S. Wales only.
[c] Statistical Abstract of U.S.A.
[d] Including lignite.
[e] *Chinese Year Book* (estimated for 1914).
[f] *Mineral Industry*, 1918.
[g] Figures for British Empire are from official returns, and for others from *Mineral Industry*, 1918.
[h] Figures are official, or from U.S.G.S. estimate to Aug. 15, 1920.

* Except where otherwise indicated, the metric ton of 2,204 lb. is used in this monograph.

TABLE II

Pre-War Consumption, Export and Import of Coal in Countries (1913)

In million tons (metric)

	Consumptions.	Exports	Imports
British Empire:			
Great Britain and Ireland	192·18	99·95	—
British Dominions	65·26	6·69	—
Total	257·44	106·64	—
Foreign:			
*Austria-Hungary	59·66	7·72	15·7
*Belgium	26·72	4·98	8·86
*France	58·25	1·36	17·71
*Germany	254·59	34·57	6·24
*Italy	11·01	0·19	10·05
*Russia	41·00	0·10	7·73
*Spain	6·71	0·01	2·30
United States	498·95	19·98	1·98
British Dominions (Analysis):			
Australia	8·81	2·13	—
Canada	30·63	1·48	17·21
*India	15·94	0·77	0·64
*New Zealand	2·18	0·21	0·48
*South Africa	7·70	2·10	0·06
	65·26	6·69	18·39

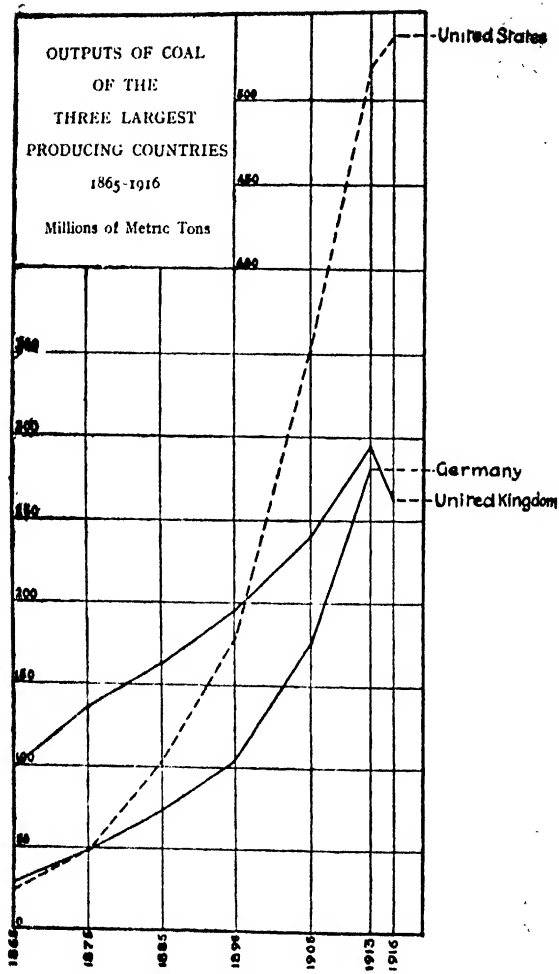
(Compiled from Official Returns of each country.)

* Calculated, Production + import − export = consumption.

Estimate of the Actual and Probable Coal Reserves of the British Empire and of Other Countries in million tons (metric)

Compiled from *The Coal Resources of the World*, 1913 [2]

—	Actual Reserves. Class of Coal. A. Anthracite Coals, including some dry Coals.	Actual Reserves. Class of Coal. B. and C. Bituminous Coals.	Actual Reserves. Class of Coal. D. Sub-Bituminous Coals, Brown Coals and Lignite.	Probable Reserves. Class of Coal. A. Anthracite Coals, including some dry Coals.	Probable Reserves. Class of Coal. B. and C. Bituminous Coals.	Probable Reserves. Class of Coal. D. Sub-Bituminous Coals, Brown Coals and Lignite.	Total.	
British Empire:								
Great Britain and Ireland	11,344	130,155	—	13	48,021	—	189,533	
Canada	675	29,161	384,968	1,483	254,500	563,482	1,234,269	
Newfoundland	—	—	—	—	500	—	500	
Australia	99	1,971	219	560	130,279	32,414	165,572	} Oceania 169,033
New Zealand	—	389	612	—	522	1,863	3,386	
British North Borneo	—	5	—	—	70	—	75	
India	—	221	225	—	76,178	2,377	79,001	
Africa	2	343	74	11,660	44,090	—	56,769	} Does not include 80 million tons given as a low estimate for S. Nigeria, a figure which might possibly be raised to 4,000 million tons
Total	—	—	—	—	—	—	1,729,105	
Other countries:								
United States	—	—	—	10,684	1,955,521	1,863,452	3,838,657	
Germany	—	94,865	9,313	—	315,110	4,668	423,356	
Austria-Hungary	—	2,074	12,585	—	8,121	1,913	55,593	
France	581	3,622	301	2,690	9,058	1,331	17,583	
Belgium	—	—	—	—	11,000	—	11,000	
Russia	—	57	12	37,599	20,792	1,646	60,106	
Spain	1,050	4,776	394	585	1,590	373	8,768	
Spitzbergen	—	—	—	—	8,750	—	8,750	
Bosnia and Herzegovina	—	—	1,700	—	—	1,976	3,676	
Netherlands	50	159	—	270	3,923	—	4,402	
China	8,883	9,783	—	378,581	597,740	600	995,587	
Japan	5	896	67	57	6,234	711	7,970	
Manchuria, Siberia	—	409	—	69	66,765	107,844	175,087	
Indo-China	—	—	—	20,002	—	—	20,002	
Netherland India	—	40	734	—	200	337	1,311	
Persia	—	—	—	—	1,858	—	1,858	
Other countries	—	—	—	—	—	—	34,662	
Grand Total	—	—	—	—	—	—	7,397,553	Including S. Nigeria


OUTPUTS OF COAL
OF THE
THREE LARGEST
PRODUCING COUNTRIES
1865-1916
Millions of Metric Tons
United States
Germany
United Kingdom
500
450
400
300
250
150
200
150
100
50
0
1865
1875
1885
1895
1905
1913
1916

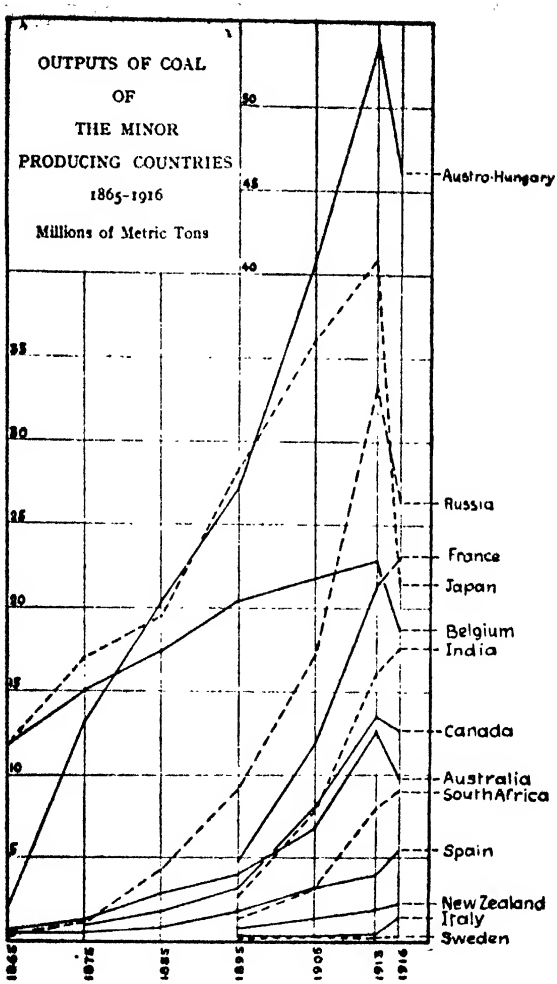

OUTPUTS OF COAL
OF
THE MINOR
PRODUCING COUNTRIES
1865-1916
Millions of Metric Tons
50
45
40
35
30
25
20
15
10
5
1865
1875
1885
1895
1905
1913
1916
Austro-Hungary
Russia
France
Japan
Belgium
India
Canada
Australia
South Africa
Spain
New Zealand
Italy
Sweden

TABLE IV

Estimate of the Coal Reserves of the World, in Continents, with Special Reference to those of the British Empire

In million tons (metric)

—	Class A.	Classes B and C	Class D.	Totals.	British.
	Anthracite Coals, including some dry Coals	Bituminous Coals.	Sub-bituminous Coals, Brown Coals and Lignites.		
Oceania: Total	659	133,481	36,270	170,410	—
British	659	133,236	35,138	—	169,033
Asia: Total	407,637	700,098	111,851	1,279,586	—
British	—	76,390	2,602	—	79,001
Africa: Total	11,662	45,123	1,054	57,839	—
British	11,662	45,033	74	—	56,769*
America: Total	22,542	2,271,080	2,811,906	5,105,528	—
British	2,158	283,601	948,450	—	1,234,269
Europe: Total	54,340	693,162	36,682	784,190	—
British	11,357	178,176	—	—	189,533
Total	496,840	3,902,944	2,997,763	7,397,553	—
British	25,836	716,505	986,264	—	1,728,605

(Compiled from *The Coal Resources of the World*, 1913) [2].

* This figure does not include the sub-bituminous coal of the new coal-field of Udi-Okwaga in Southern Nigeria, with an area amounting to about 1,800 sq. miles, over which known outcrops occur.

CHAPTER II

BRITISH SOURCES OF COAL SUPPLY

UNITED KINGDOM

England and Wales

South Wales [No. 1 on Map]. This coal-field stretches east and west from Pontypool to St. Bride's Bay. The principal portion, fifty-six miles long, occupies part of the counties of Monmouth, Glamorgan, Brecknock, and Carmarthen, and is connected beneath Carmarthen Bay with the small western portion in Pembrokeshire. The field covers 842 sq. miles, of which 33 miles only lie in Pembrokeshire (Strahan).[1]

The structure of the main field is synclinal; the coal-bearing measures outcrop all round the edges of the basin, except where covered by the waters of Swansea and Carmarthen Bays and by newer rocks for a short length at Llantrisant, and are bounded by the outcropping older rocks. The strata dip much more steeply on the southern than on the northern outcrop, while at each end of the basin the dip is slight. An anticlinal fold, roughly parallel with, and comparatively near, the southern edge of the basin, runs east and west from Risca through Swansea Bay, developing a trough to the north and one to the south, and raising the lower coal to an accessible position over a considerable area. In the west of Glamorgan and in the south-east of Carmarthen there are certain areas where the productive coal-measures lie at a greater depth than 4,000 ft. and are still unproved.

The Coal-Measures vary in thickness from about 4,000 ft. to 12,000 ft. and occur in the following order:

(1) Upper series, consisting largely of shales with several bituminous coal-seams.

[1] E. Hull gives a superficial area of 906 sq. miles and H. S. Jones nearly 1,000 sq. miles.

(2) Pennant series, mainly sandstone, with coal-seams only in the west.

(3) Lower series, chiefly shales, with the greatest development of coal and, near the northern outcrops, beds of ironstone.

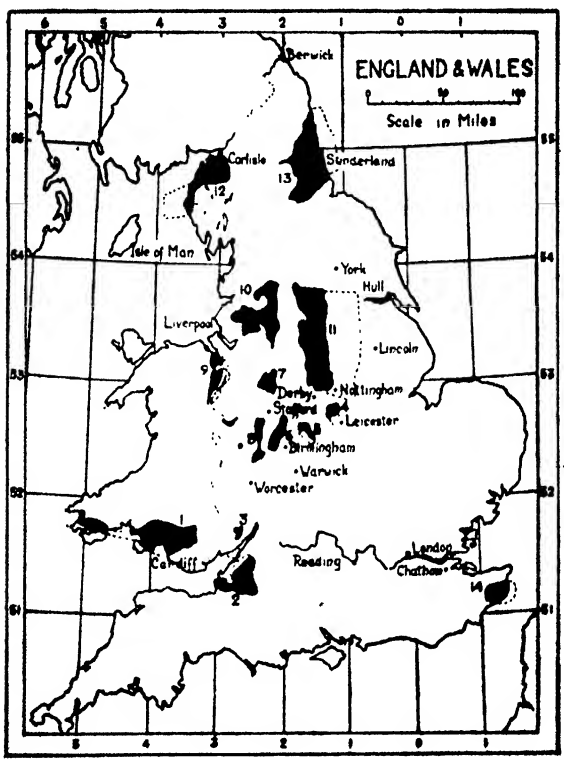
Twelve seams, aggregating 42 ft. in thickness, occur in the east of the field, while in the south and west of Glamorgan the number increases to upwards of 40, with about 120 ft. of coal. In the eastern part of the Pembroke field, where the lower series only is present, 8 seams, with 21 ft. of coal, occur; but in the west, where a part also of the Pennant series remains, there are 18 seams, with 33 ft. of coal.

The coal ranges in character from bituminous house-coal, through the famous Welsh steam-coal to anthracite of remarkable purity. Anthracite occurs in the north-western districts of the main field, and attains its greatest purity near Kidwelly, while in Pembrokeshire the coal is almost wholly anthracite.

A characteristic feature of this coal is the gradation that takes place from one class of coal to another, a gradation both vertical and lateral. Thus, in the anthracite area, each seam, in any one section, is in general, but not in every case, more anthracitic than the one above, and each becomes more anthracitic as it approaches the northern and north-western margin of the field. It follows from this that in the same mine the upper seams may yield house-coal and the lower seams steam-coal; or, if the upper seams yield steam-coal, the lower may yield anthracite. There is, therefore, no clear line of demarcation of the anthracite field.

The cause of anthracitization, as regards the South Wales coal-fields, has long been a matter of surmise and speculation. The subject has of recent years been studied with great care by Aubrey Strahan and W. Pollard [15], who have endeavoured to prove that this anthracitic character of the coal is due to the original composition of the vegetable matter forming the coal, and not to extraneous influences, such as extraordinary static or dynamic pressure or regional heat, however caused. The comparison made of the various coals in this investigation appears to be based on chemical analysis alone, and the main argument relies on the remarkable freedom

of Welsh anthracite from ash impurity. If this were the determining factor, might it not be expected that the purer layers of coal in any seam would approach more nearly to



anthracite than those containing more ash ? The analysis given on page 73 of the Memoir cited shows, on the contrary, that the purer layers of coal, with 2·66 per cent. of ash, in the Three-Quarter Coal from Monmouthshire, are further removed from

anthracite than are the dull layers with 6·44 per cent. of ash. The facts and arguments presented in this Memoir are instructive and interesting, but the conclusion arrived at is not altogether satisfying.

The relative proportions of the three main classes of coal were estimated by W. T. Lewis for the Royal Commission on Coal Supplies (1904), thus: Bituminous, 30·42 per cent.; steam, 47·31 per cent; anthracite, 22·27 per cent.

The output in 1880 amounted to 21,165,580 long tons and in 1913 to 56,830,072 tons. The coal reserves, as estimated by the Royal Commission of 1904, after deducting the coal produced, were in 1913.

	Million Tons.
In seams of 1 ft. and over to a depth of 4,000 ft. . . .	36,000
In seams of 2 ft. and over at depths between 4,000 and 6,000 ft.	1,500

Bristol and Somerset [No. 2 on Map]. - This coal-field on its eastern edge stretches for 25 miles from Wickwar in the north to near Frome in the south, and occupies to the west of this line an area roughly triangular in shape. An east and west faulted anticlinal zone, which crosses the River Frome 2 miles north of Bristol, divides the field into the small northern basin lying chiefly in Gloucestershire, and the large southern basin lying chiefly in Somerset. Two small outlying basins have been proved to the north and south of the mouth of the Avon.

The general structure of the field may be considered as the result of an east and west synclinal fold crossed by another running N.N.E. to S.S.W. The effect of the series of folds to which these belong, on the South Wales and Forest of Dean coal-fields, is briefly outlined by H. S. Jevons [11/p. 77]:

Succession of Strata near Bristol. (*After R. Etheridge as quoted by Hull*) [10/p. 68].

		Feet.
Trias (Keuper)		
Coal-Measures . .	Upper series, with 22 coal-seams, of which 9 average 2 ft. in thickness and upwards	3,000
	Central or Pennant Sandstone, etc., 5 coal seams	1,725
	Lower shales, 36 coal-seams . . .	2,000
Millstone Grit . .	Hard siliceous grits, etc. . . .	950
Carboniferous Limestone	Well shown in the Avon gorge . .	2,338

The Carboniferous Limestone attains a thickness of 3,000 ft. on the southern edge of the field in the Mendip Hills, but in a distance of only 30 miles to the west, in the Forest of Dean, it dwindles to less than 400 ft.

Estimate of Coal Reserves (*Hull*, 1903)

Area.—Visible	45	
Concealed by newer formations	105	
		150 sq. miles.
Greatest thickness of measures with coal . . .		9,000 ft.
Seams of 2 ft. and over, 20, aggregate thickness .		71 ,,
Total quantity coal down to 9,000 ft., in million tons .		6,036
Quantity of coal down to 4,000 ft in million tons .		4,151

Strahan's estimate of the coal reserves below 4,000 ft., in *The Coal Resources of the World*, is 4,260 million tons.

Good house, rich gas, coking, manufacturing and steam coals are produced, and the annual output of some sixty collieries is about 1,300,000 tons.

The anticlinal ridge of the Mendips forms the southern boundary of the field, and it is inferred that to the south of these hills a coal-field, concealed beneath the Lias and New Red Marl of the Brue valley, may stretch as far south as Cannington Park. Similarly, an extension eastward in the vicinity of Bath has been conjectured.

Forest of Dean [No. 3 on Map]. This interesting coal-field lies in Gloucestershire, west of the Severn, and consists of an irregularly shaped basin, 34 sq. miles in extent, encircled by Millstone Grit (so-called) and Carboniferous Limestone outcropping above the level of the enclosed Coal-Measures.

The following is the sequence of formations in descending order:

Coal-Measures, with 15 seams			2,765 ft.
	Unconformity		
Carboniferous Limestone	Drybrook Sandstone, so-called Millstone Grit . . .		455 ft.
	Main Limestone	Whitehead limestone, Crease limestone . Lower dolomite	480 ft.
	Lower Limestone Shales .		165 ft.
Old Red Sandstone			8,000 ft. or more.

T. F. Sibley [14] regards the so-called Millstone Grit as the upper strata of the Carboniferous Limestone and terms it Drybrook Sandstone. It is conformable with the underlying strata, but unconformable with the overlying Coal-Measures.

The general dip of the basin is from the margin toward the centre. On the east the prevailing dip of the Coal-Measures is much less than that of the steeply-inclined older rocks; on the north and west the difference of inclination is slight.

The coal is found in 15 seams over 1 foot thick, of which eight are 2 ft. and more in thickness and aggregate 24 ft. of coal. The actual reserve of coal is estimated at 200 million tons, in addition to which there is a problematical 100 million tons in the northern part of the field.

Leicestershire [No. 4 on Map]. This coal-field lies to the south of the Trent valley with Ashby-de-la-Zouche as its centre. The "visible" portion occupies 30 sq. miles, and a "concealed," but proved extension is estimated to occupy 55 sq. miles. On the western side of the field the strata rise and are overlaid unconformably by the Trias.

In the central part of the field 33 seams of 1 ft. and over aggregate 94 ft.; in the southern extension 22 seams total 91 ft.

The "actual" reserve of coal is estimated to be 2,480 million tons.

Warwickshire [No. 5 on Map]. This coal-field is, with the exception of the Kent field, the nearest to London. It lies in the north of the county, and extends from near Tamworth in a south-east direction to Wyken, a distance of 15 miles. The visible Coal-Measures, at their north-western end, occur as a syncline 4 miles wide, bounded on the west, north and east by faults, which bring in the New Red Sandstone. Thence they trend S.S.E. as a narrow strip on the west side of Atherstone and Nuneaton, and are bounded on the east by an outcrop of older rocks, which are partly overspread by Trias. To the west they dip beneath and are concealed by the so-called Permian and the Trias strata, but are "proved" and "partly proved" over an area estimated by Lapworth and Sopwith to occupy 32 sq. miles. The "visible" field has an area of 24 sq.

miles, and contains 10 seams over 1 ft. thick, with an aggregate of 40 ft. Five of these seams are workable in the north. Southward, the sandstones and shales intervening between the seams and amounting to 120 ft. thin out, and the seams unite to form a single seam 26 ft. thick at Wyken, as occurs in the "Ten-yard" coal of South Staffordshire. Serious faults are absent. The peculiarly persistent thin bed of *Spirorbis* limestone is found in the upper coal strata.

The estimated "actual reserve" is about 1,445 million tons.

South Staffordshire [No. 6 on Map] The coal-bearing area of this district stretches from the Clent Hills northward to Brereton, near Rugely, a distance of 21 miles, and has an average width of 7½ miles. The estimated area, including the unproved portion concealed by newer strata, is 150 sq. miles. The "visible" coal-field lies between two nearly parallel faults trending north and south, beyond which, as well as to the north and south, newer rocks occupy the surface.

A ridge of Upper Silurian rocks, which formed the original margin of the basin, limits the field on the south.

Coal in the hidden portions has been opened out at Sandwell in the east and in Cannock Chase in the north-west.

There are on an average eleven coal-seams in the north, aggregating 67 ft. Nine of these seams, proceeding southward, unite to form the famous "Ten-yard" or "Thick Coal" seam, 30 ft. thick near Dudley and 24 ft. at Sandwell. In the southern district 6 seams, inclusive of the composite "Thick Coal," aggregate 65 ft. The coal in general is suitable for domestic, smelting and manufacturing use, but never has the character of true steam-coal. The great industrial development round Birmingham, Dudley and Wolverhampton owes its growth to the rich deposits of coal and iron in this field.

North Staffordshire [No. 7 on Map] The coal-seams of this basin lie within a roughly-shaped triangle, whose apex is to the north near Congleton Edge. The area is 110 sq. miles, a further 18 sq. miles being occupied by the outlying Cheadle area to the east. The Coal-Measures of the main field are bounded on the east by the Millstone Grit and on the north-west by the Red Rock Fault of Cheshire, which throws down Triassic rocks. To the south the Coal-Measures are overlaid by and may con-

tinue beneath the newer formations as workable extensions (*see Concealed Coal Fields, below*).

The structure of the field, broadly stated, is a trough, constantly widening southward, of which the western lip bends over an anticlinal fold, and dips in a narrow strip to the Red Rock Fault. The sequence of strata in this neighbourhood is as follows:

Trias . . .	Bunter, pebble beds
Carboniferous . .	Keele group (so-called Permian), Red sandstone and marls Newcastle, or Halsowen group, Sandstone formation. Etruria group, Red marls Upper Coal Measures Lower Coal-Measures

In 30 coal-seams over 2 ft. thick found in this field there is 140 ft. of coal; other seams, ranging from 1 to 2 ft. thick, bring the total thickness up to 150 ft.

The Coal-Measures of the Cheadle field are bounded on the north by older rocks, but extend southward as a concealed field of unknown area beneath the Trias. Strahan states that 17 seams, aggregating 65½ ft., occur, but are varied and often individually absent, one only persisting over the entire field.

The estimated "Actual Reserve" of South and North Staffordshire, inclusive of Cheadle, to a depth of 4,000 ft., is about 7,150 million tons, and between 4,000 and 6,000 ft. 2,955 million tons.

Shropshire and Worcestershire [No. 8 on Map].—These counties include the coal-fields of Coalbrook Dale and the more or less unimportant coal-fields of the Forest of Wyre, the Clee Hills, Shrewsbury, Leebotwood and Dryton.

Coalbrook Dale, situated in Shropshire between Wolverhampton and Shrewsbury, is a small triangular coal-field stretching from south of Ironbridge northward to Newport, and has an area of 18 sq. miles. The coal-bearing measures have a general dip to the east; they are bounded on the north-west by a great downthrow fault, on the south-west by Silurian rocks, and disappear to the east beneath newer rocks, formerly classified as Permian.

From the investigations of M. W. T. Scott [13] and D. Jones [12] it would appear that denudation occurred during the coal

period, and that the Upper Coal-Measures, with the *Spirorbis* limestones, were laid down in the hollows of the denuded surface and, in parts, beyond the limits of the folded Lower Coal-Measures. The unconformability thus formed is known locally as the "Symon Fault" [9].

The field is much faulted. The Lightmoor fault, trending N.E.–S.W., bisects the field, and to the west of this fault the coal is practically exhausted. Six seams, aggregating 27 ft. of coal, have been worked.

The coal-field beneath the Forest of Wyre extends from the northern end of the Abberley Hills to the west of Bridgnorth, and then continues northwards as a narrow belt by the banks of the Severn to Coalbrook Dale coal-field. The area of the field is almost equal to that of the Forest of Dean.

The Coal-Measures lie on Old Red Sandstone, and are overlaid by the so-called Lower Permian rocks, which exhibit a breccia resembling the débris from glaciers.[1] This bed is now regarded as a delta fan and not glacial. Seams, correlated with those of Coalbrook Dale, aggregate from 7 to 15 ft. of coal.

Some miles to the west of the Forest of Wyre small patches of coal, capped by a bed of basalt, are found on the summits of the Titterstone and Brown Clee Hills, in Leebotwood and Dryton.

Shrewsbury coal-field occupies a crescent-shaped belt, 18 miles long and seldom more than a mile wide, from a point east of Shrewsbury to the Severn, near Alberbury. The Coal-Measures rest directly on Cambrian and Silurian rocks, and are overlaid by the so-called Permian rocks. The upper Coal-Measures here, as in Coalbrook Dale, the Forest of Wyre, Warwickshire and Lancashire, contain the persistent *Spirorbis* limestone, a bed seldom more than a foot thick. The three known coal-seams have a total thickness of 6 ft.

The estimated coal reserve of Shropshire and Worcestershire is 360 million tons.

North Wales [No. 9 on Map].—The visible portion of this coal-field consists of two areas separated by the great Bala fault, an area of 47¾ sq. miles on the north-west lying in Flint-

[1] See *Glacier Boulder Beds in South Africa, India, and Australia.* The Lower Coal-Measures of N.S. Wales occur between marine formations, both of which contain undoubted glacial boulders.

shire, and an area of 56 miles on the south lying in Denbighshire. Rocks older than the Coal-Measures bound the field on the west, while Triassic rocks conceal the continuation of the Coal-Measures to the north-east under Wirral and to the east in Cheshire. In the concealed portions of Denbighshire the productive measures are overlaid by the equivalents of the Etruria marl, the Newcastle series, the Keele series of Staffordshire, and finally by the Bunter beds.

The coal-seams of these counties have a general correlation and only slight differences over the field. In Flintshire 12 to 14 seams have a total thickness of 58 ft.; in the northern part of Denbighshire, 17 seams aggregate 61 ft., which in the south of the field dwindle down to 37½ ft. in 16 seams of lower quality.

The principal seams in Flintshire, in descending order, are the Four-Foot (Coal and Cannel), Hollin (Coal with Cannel), Brassy, Main (7′ 0″), and Lower Four-Foot (in some places Cannel). Those of Denbighshire are the Drowsalls, Powell, Two-yard, Brassy, and Main. A special feature of the Flintshire field is the Cannel coal found at Leeswood, near Mold and other places, and celebrated for its high gas-producing quality.

The total area of the coal-field in Flintshire, including the small area of Neston, is 87½ sq. miles, with an estimated reserve of 1,080 million tons; the area in Denbighshire is 91 sq. miles, with 1,450 million tons.

Lancashire and Cheshire [No. 10 on Map].—The bulk of this coal-field lies in the south of Lancashire within an area of extremely irregular outline. It stretches in an east to west direction from Stalybridge to Bickerstaffe, a distance of 32 miles. Spurs due to faulting strike out to the north and the south from the main body, and a narrow strip to the south forms the Cheshire area. The visible coal-field, according to Strahan [2/p. 206], covers 484 sq. miles, and the coal-bearing measures continue to the south beneath newer rocks over an area of 70 sq. miles.

The Coal-Measures were originally continuous with those of the Yorkshire field, but are now separated from the latter by the denuded surface of the Pennine Chain. The structure of the field is complicated, but may be broadly described as a basin of which the northern and eastern edges rest on the Millstone

Grit, while the western margin is defined by a downthrow fault, running north and south through Bickerstaffe, and throwing down the New Red Sandstone. The southern segment is hidden beneath the Mersey Valley. Faults are numerous, and the measures are in general steeply inclined.

The middle Coal-Measures contain the following coals (Strahan):

District.	No. of seams.	Aggregate thickness of coal.
Northern	15	46½ ft.
South-eastern	19	70 ,,
South-western	21	75 ,,

Well-known seams among these are the Arley Mine, Wigan Cannel coal, Ravenhead, Rushey-park, and St. Helen's Main. Many collieries in this field have long operated at great depths, Pendleton colliery, near Manchester, for instance, being 3,483 ft. deep.

The "actual" reserve of coal is estimated to be 5,600 million tons. "Probable" reserves in the Cheshire basin and "possible" reserves around Chester, the Wirral, and Liverpool are referred to under *Concealed Coal-Fields* below.

Yorkshire, Nottinghamshire and Derbyshire [No. 11 on Map].—This coal-field is the most extensive in England. It extends from Leeds to Nottingham, a distance of 60 miles, and is roughly defined on the west by a line drawn from Halifax to a point 4 miles east of Derby, on the east by an arbitrary line running east of Pontefract, Doncaster, Worksop, Mansfield, and Nottingham, beyond which the measures are hidden beneath unconformable Permian strata. The width is, therefore, still unknown, but assuming an arbitrary limit to the east, the area is estimated as follows:

Visible coal-field	808	sq. miles.
Concealed but proved coal-field	568	,, ,,
Concealed but partly proved in the Trent valley	760	,, ,,
Total	2,126	,, ,,

The Coal-Measures outcrop on the northern and western margins, and dip at a gentle angle beneath the Permian cover for an unknown distance to the east, in which direction the structure of the field is still undetermined. Mining develop-

ments of an extensive kind have, however, been carried out in recent years within the concealed area to the east and south of Doncaster.

Coal-seams occur as under:

District.	No. of seams.	Aggregate thickness.
Northern area	15	52 ft.
Central area	18	40 „
Southern area	21	50 „

The chief seam is the Barnsley Bed, which is in places from 7 to 10 ft. thick, and has been worked from Barnsley to Nottingham. Other well-known seams are the Parkgate or Deep Hard, the Flockton or Deep Soft, the Silkstone or Black Shale, and the Warren House.

The output in 1913 reached nearly 75 million tons. The reserve of coal over the proved coal-field in seams 1 ft. and more in thickness was estimated by A. C. Briggs for the Royal Commission on Coal Supplies in 1904 as follows:

West Yorkshire	8,367,385,000
South Yorkshire	10,770,620,000
Derbyshire and Nottinghamshire . .	7,360,725,000
Total in long tons	26,498,730,000

But the figures given by A. Strahan [2/p. 611] in 1913 are:

Reserve to 4,000 ft. . . .	40,254,216,000 metric tons.
„ from 4,000 to 6,000 ft .	985,000,000 „ „

Cumberland [No. 12 on Map].—The visible coal-field in this county follows the coast-line from St. Bee's Head to Maryport, a distance of 16 miles, and has its greatest width of 6 miles at Workington. It then continues north-east as a strip, about 10 miles long, from near Maryport to a point south of Wigton. Outcrops of Millstone Grit and Carboniferous limestone bound it on the south-east and east, and faults cut it off on the south and north. Its limits westward beneath the sea are unknown, but at Whitehaven coal is being worked at a distance of 4 miles from the shore.

Beyond the northern limits of the "visible" field a concealed coal-field of much greater area possibly exists eastward and northward beneath the mantle of Permian measures.

as far as Carlisle, and beneath the Solway Firth to the small visible coal-field of Canonbie in Dumfriesshire.

In the northern part of the known field there are 10 seams, in the central part 20, and in the southern part 11, aggregating, respectively, 28, 57, and 45 ft. of coal. Inclusive of undersea coal within 5 miles of the coast the estimated "actual reserve" is 2,180 million tons, of which 40 per cent. is in the land area. An additional "probable reserve" of 1,200 million tons is estimated to lie between 5 and 12 miles from the coast under the sea.

Durham and Northumberland No. 13 on Map.—This important coal-field lies chiefly in the county of Durham. Its outline is triangular, with the apex to the north at the mouth of the River Coquet and the eastern side on the North Sea, beneath which the measures extend. Its length from north to south is over 50 miles, and its width ranges from 5 miles in the north to 30 miles in the south. Permian rocks overspread the Coal-Measures on the Durham coast and along the southern margin. The area of the field is computed as follows:

Coal-field exposed	. . .	588 sq. miles.
,, under Permian strata	. . .	125 ,, ,,
,, under the sea	. . .	180 ,, ,,
Total	. . .	893 ,, ,,

The general structure of the field is that of a trough, with the longer axis running north and south. The western margin rises towards and rests against the Pennine Chain, and the measures tend to rise in the north-east towards the floor of the sea, and in the south as a sub-outcrop beneath the overlying Permian rocks.

Sixty seams have been identified, of which from 20 to 23, 1 ft. and more in thickness, are workable, and aggregate from 46 to 60 ft. of coal. The estimated "actual reserve" is 11,000 million tons, of which about 25 per cent. is under the sea. The output in 1913 was 56,352,264 statute tons.

In the Carboniferous Limestone lying on the west of the Coal-Measures in Northumberland there are irregular occurrences of a series of coal-seams which are the equivalent of the

Lower Coal Series of Scotland. The seams number from 6 to 8, with an aggregate thickness of about 18 ft., and were estimated by Lindsay Wood to contain 158 million statute tons in the exposed portions. A further quantity of 2,455 million statute tons was estimated to underlie unproved areas, and is regarded as a "possible reserve." Some of these thin seams must, however, lie at great depth, and it is open to question whether all of this amount can be placed in the category of available coal.

Kent [No. 14 on Map]. This concealed coal-field lies in the east of Kent, and is entirely covered by Cretaceous and Jurassic rocks, varying in thickness, roughly, from 800 to 1,400 ft.

Geological deductions, indicated by De la Beche in 1846, and more fully elaborated by Godwin Austin in 1855, led to a belief in and finally to a search for this field. Boring on the site of the Channel Tunnel works proved the accuracy of these deductions by the discovery of coal in 1890. Subsequent boring has proved a coal field of large extent, and the sinking of deep shafts and mining operations have demonstrated the value of the coal deposits, in spite of many difficulties, principally due to the presence of water-bearing ground in the Cretaceous rocks overlying the Coal-Measure. Similar, and at times even greater difficulties, it may be pointed out, have been encountered and overcome in Belgium, the north-east of France, Westphalia, and some of the concealed parts of the coal-fields of England, with less technically perfect methods than are now available.

The writer is greatly indebted to Professor William Galloway for having placed at his disposal much information regarding this field for the descriptions of its salient features, which is here largely made use of.

The surface of the Coal-Measures dips southwards and south-westwards. Its average depth below sea-level in a line drawn from the South Foreland to Sandwich at a distance of about 2 miles from the coast is a little over 800 ft. Near Bishopsbourne it is 1,113, at Elham 1,323, and at Folkestone 1,374 ft. The thickness of the Coal-Measures in the Ripple borehole was 2,248 ft., and at Oxney, near St. Margaret's,

2,730 ft. were bored through without reaching bottom. These measures, according to the late E. A. N. Arber, represent a thick development of the Middle Coal-Measures, and of what are known as the Transition Measures, which lie between the Middle and Upper Coal-Measures proper, thus resembling, as in the fossil flora, the measures of the Pas de Calais coal-field. Nearly all the boreholes show that the seams of coal are more numerous and individually thicker towards the base of the measures than higher up, but for reasons not yet apparent no convincing correlation of the seams found in the various boreholes has been established, except in the case of the seams found in Barfreston and Waldershare boreholes and Snowdown deep pit, and in that of the seam now being worked in Snowdown and Tilmanstone collieries, in a distance of about 4 miles.

Kent coal-field lies in a roughly elliptical, but unsymmetrical trough in the older rocks. The major axis of the trough runs from a point slightly north of Chislet, through Dover, and continues for an unknown distance into the Channel. Starting from the most northern point of the major axis, the margin of the field curves round north eastwards, gradually trending southwards, until it passes under the sea near Sandwich, and is thereafter supposed to turn more and more southward. From the same point on the axis the western curve of the ellipse turns westward, trending rapidly southward, and passes not far west of Bishopsbourne, Elham and Folkestone, where it disappears under the sea.

The length of the coal-field from Chislet to Dover is 15 miles; its width from Ebbsfleet to Elham is about 10 miles, and increases southward from that line. Its area under dry land is, according to Strahan, about 150 sq. miles, to which has to be added a submarine area of 50 sq. miles in an accessible strip parallel with the coast.

The Ripple and Barfreston boreholes, 4½ miles apart, and practically on the same line from east to west as Tilmanstone and Snowdown collieries, may be taken as generally typical of the coal-field, and are as follow:

Ripple.		Barfreston.			
Depth from surface. Ft.	Thickness of seams. Ft. In.	Depth from surface. Ft.	Thickness of seams Ft. In	Good Coal. Ft. In.	Quality of coal in Barfreston bore. [11/p. 168].
2,025	6 2	1,452	5 3	3 8*	Soft, friable, coking
2,077	1 11	1,850	2 0	—	?
2,185	6 10	1,914	2 6	—	?
2,410	4 0	2,107	1 11	4 0†	Excel. domestic
2,637	1 11	2,262	6 9	6 9	Excel. steam
2,703	4 8	2,944	4 7	4 5	Steam and domestic
2,744	9 4	3,261	4 0	1 0	Medium steam
2,877	3 8	3,318	9 6	9 6	Navigation steam
2,992	1 11	3,328	—	—	—
3,170	Limestone				
Total	49 5		[illegible] 3		

* Beresford seam † Snowdown Hard seam.

Analyses of Coal

	Beresford	Hard	Seam at 2,944 ft.
Moisture	1·30	0·87	0·83
Volatile matter	30·41	20·98	20·87
Fixed carbon	62·85	68·10	75·75
Ash	5·43	10·05	2·55
	100·00	100·00	100·00

The chemical constitution of the coal, as shown by these analyses, is excellent. Galloway says, "The seams found in Snowdown deep sinking below the Beresford are a little harder than the latter, but all of them partake more of the nature of the seams found in coal-fields between Kent and Rhenish-Westphalia, inclusive of the latter, than of those found in most of the coal fields worked in other districts of this country. Some of the seams found in the deeper boreholes contain as little as 14 per cent. of volatile matter, and will, therefore, as far as their chemical constitution is concerned, rank as first-class steam-coals of the Welsh type. It remains to be seen whether their physical constitution will entitle them to be retained in that category."

Tilmanstone and Snowdown collieries have produced coal since 1913; Chislet colliery is now producing a little coal, and it is understood that the sinking at Guilford colliery has now nearly reached the Coal-Measures.

Tilmanstone and Snowdown collieries have produced the following quantities from the Beresford seam:

Year.	Tilmanstone Tons.	Snowdown. Tons.
1913	40,054	2[illegible],046
1914	82,[illegible]	58,523
1915	41,5[illegible]	104,120
1916	10[illegible],040	115,109
1917	135,[illegible]	134,089
1918	1[illegible]	10[illegible],057
	[illegible]	545,180

The development of this coal-field has, considering its geographical advantages, been singularly slow. For one reason and another the necessary financial support has been difficult to obtain, but the potentialities of the field must gradually be recognized, and its resources utilized in many ways and directions.

Strahan, following conservative lines, and allowing an aggregate thickness of only 10 ft of coal over the field, arrives tentatively at a reserve of 2000 million tons. H. S. Jones, with later information available and apparently on good grounds, trebles this quantity, and, in addition, indicates a "probable" reserve of 3,600 million tons of coal.

Concealed Coal-Fields in England

The wholly concealed coal-field of Kent has now been proved to a considerable extent by boring, and has entered the list of producing coal-fields. Its general characteristics have been already described.

At Burford, in Oxfordshire, a bore-hole put down in 1875–7 reached Coal-Measures at 1,184 ft., and is said to have passed through some coal. More recently at Batsford, in Gloucestershire, Coal-Measures were reached at 1,021 ft., and were found to rest upon Silurian rocks. Jurassic and Triassic rocks extend over the district, and the existence of productive Middle Coal-Measures is still undetermined.

Extensions of known coal-fields to greater depths, either through the dip of the measures, or through downthrow faults, beneath a covering of more recent rocks, constitute the other

known concealed coal-fields of England. These are in most cases being gradually approached or proved by deeper borings or sinkings. For the few details here given regarding them, we are indebted to the short but lucid descriptions to be found in *The Coal Resources of the World*, by Strahan.

South Staffordshire.—To the west of the known coal-field of South Staffordshire, towards Coalbrook Dale and north of a line drawn from Bridgenorth to Sedgley, Lapworth considered there was a coal-field with a probable extent of 220 sq. miles. Exclusive of coal supposed to lie at a greater depth than 4,000 ft. or to be otherwise unavailable, he estimated a "probable reserve" of about 8,500 million tons. A "possible reserve" may also exist in ground to the south of the above area.

On the eastern side of South Staffordshire, towards the Warwickshire coal-field, an area is estimated by Lapworth to cover 292 sq miles, to have on an average 35 ft. of coal, and to contain a reserve of 10,000 million tons. But the covering of Triassic and other unproductive rocks is thick, and this large quantity of coal must for the present be regarded only as a "possible reserve."

North Staffordshire.—Lapworth has estimated that on the southern margin of the North Staffordshire coal-field, a sub-Triassic coal-field, extending from the north-western boundary fault of the known field, eastward almost to Uttoxeter, and as far south as Stone, has an area of about 96 sq. miles and a coal content of nearly 6,000 million tons. Only half, however, of this quantity is supposed to lie at a less depth than 4,000 ft. and to come within the category of "probable reserve."

Cheshire Basin.—In the country between the coal-fields of North Staffordshire, Denbighshire and Lancashire, coal probably exists. But the depth is prohibitive except in parts towards the margins where there is a "probable reserve" of 30 million tons. To this is added 120 million tons, probably raised by faults to within 4,000 ft. or less of the surface along the eastern and north-eastern margins of the Cheshire basin. The "probable reserve" is thus 150 million tons.

Chester, Wirral and Liverpool.—A thick covering of Triassic

and probably barren Upper Carboniferous rocks is spread over 200 sq. miles of this district reasonably supposed to be coal-bearing. A thickness of 15 ft. of coal within this area would produce nearly 3,000 million tons, but it is prudent to regard this only as a "possible reserve." Deep boring at Heswall entered unproductive strata below the Bunter sandstone.

Yorkshire, Derbyshire and Nottinghamshire. The Coal-Measures of this coal field have a general dip to the east, and finally disappear beneath an increasing thickness of Permian, Triassic and Jurassic formations. The eastern limits of this extension are still unknown, but the aggregate thickness of coal would appear so far to be maintained.

Strahan, from various considerations, reduces the estimate of 2,550 sq. miles given in 1905 as the area of the extension, to 760 sq. miles and the amount of "coal existing" from 46 million tons to a little under one-third of this figure. In this estimate the assumed thickness of coal is 20 ft.

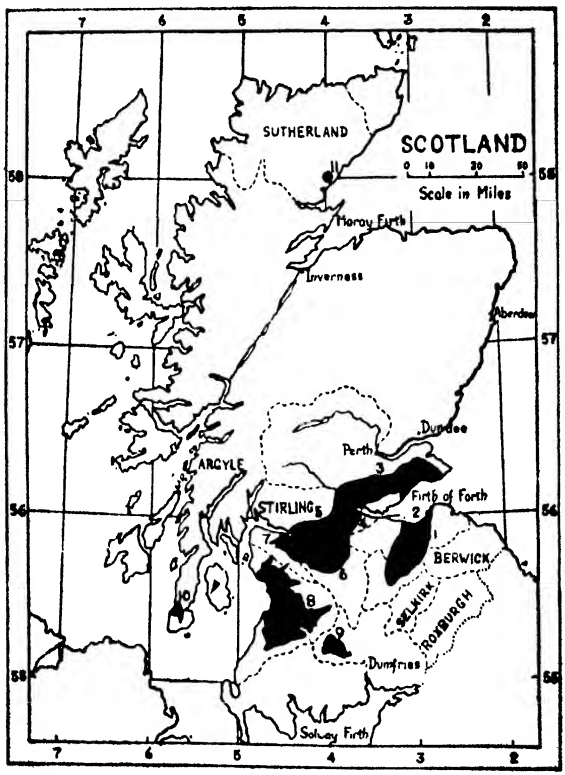
Vale of Eden and Solway Firth. On the northern side of the fault forming the boundary of the Cumberland coal field to the north, there is an area of 40 sq. miles believed to be underlaid by coal at a workable depth. On the assumption of 21 ft. of coal, an estimate of about 814 million tons of coal is arrived at, and this is regarded as a "possible reserve."

SCOTLAND

The principal coal-fields of Scotland are found in the counties of Midlothian, East Lothian, Fife, Linlithgow, Clackmannan, Lanark and Ayr. Broadly speaking, they lie in a belt stretching for over 90 miles in a north-east to south-west direction from the coast of Fife to the Ayrshire coast. The average width is 25 miles. Small fields are also found, such as Lesmahagow in the south of Lanarkshire, Sanquhar in Ayrshire, Campbelltown in the south of Argyllshire, and Canonbie in the south of Dumfriesshire. The last is possibly continuous, under the Solway Firth, with the concealed field in the north of Cumberland if it exists.

Throughout England and Wales, except in part of Northumberland, the coal-seams occur only in the Coal-Measures,

that is, in measures above the Millstone Grit. In Scotland, the principal seams occur in the same horizon, but profitable coals are also found beneath the Millstone Grit in the Carboni-



ferous Limestone and, to a less extent, in the underlying Calciferous Sandstone. These lower coals are evidently due to the existence of swamp conditions favourable at times to growth of vegetation, at a period when the areas to the south

were still covered by the sea. It naturally follows that the Carboniferous Limestone and Millstone Grit are more sparingly developed in the north than in the south. The coals of this lower series are generally thin, but are well developed around Lochgelly and Dunfermline in Fife.

The following table is from Walcot Gibson's work, *The Geology of Coal and Coal Mining* (1895):

Sequence of the Carboniferous System in Scotland

Coal-Measures	Red Sandstone	600 ft.
	Upper Coal Series	300 „
	Lower Coal Series	800 to 1,500 „
Millstone Grits	Roslin Sandstone or Moor Rock (almost barren of coals)	0 to 700 „
Carboniferous Limestone Series	Upper Series of Limestone Sandstones Shales and Coals	
	Lower Series of Limestone	
Calciferous Sandstone Series	Sandstone and Conglomerate	

Portions of the Scotch coal fields have been subjected, at widely separated periods to intrusion of igneous matter, which, as vertical dykes, add to the cost of mining, and, as sills following the beds, have destroyed large quantities of coal, particularly in Ayrshire,[1] Fife (17) and Linlithgowshire.

Scotch coals are, as a rule, bituminous, and range in quality from good to medium steam, gas, house and coking coal. Anthracite also is found near igneous intrusions in the fields of Ayrshire, Lanarkshire and Fife. Cannel coal occurs in Midlothian, Lesmahagow and west and south of Glasgow.

The Lothian Coal-Fields (No. 1 on Map). These consist of the large, deep and, at the edges, steeply-inclined trough of Midlothian, and the smaller and flatter trough of East Lothian, partially separated from each other by the Carberry ridge. The major axis of the former passes from south to north by

[1] "Edge coals" of Midlothian.

[2] The writer has observed at Trabboch Colliery, Ayrshire, intensely hardened anthracitic coal in the centre of a 6-ft. seam untouched by igneous rock, and of which the upper and lower sections remained bituminous, an effect possibly due to the passage of hot gases evolved by igneous rock.

Dalkeith and that of the latter by Tranent, the measures striking north beneath the Firth of Forth towards Fife, where they reappear.

The Midlothian field includes the Coal-Measures and the Carboniferous Limestone or "edge coal" series, and has in the upper series 15 seams of coal aggregating 40 ft., and in the lower series, where best developed, 22 seams aggregating 65 ft. [2/p. 621]. In the East Lothian field, on the other hand, the Carboniferous Limestone series only is represented, with 9 seams aggregating 31 ft. [10/p. 228]. Hull gives the total area of these fields as 95 sq. miles, but Strahan, at a later date, gives 128½ sq. miles, and an estimated actual reserve of about 3,140 million tons.

Coal beneath the Firth of Forth [No. 2 on Map].—Coals of the upper and the lower series stretch as a north and south synclinal trough beneath the Forth, and occupy a probable area of 130 sq. miles. According to the figures of Gemmell, furnished to the Royal Commission on Coal Supplies, the upper series extends over 58 sq. miles and contains 20 seams aggregating on the northern shore 65 ft., and on the southern shore 40 ft. The lower series, to a depth not exceeding 4,000 ft., may occupy 58 sq. miles, and as exposed has, on the northern shore, an average of 27 ft. of coal, and on the southern 44 ft. Beneath the 4,000 ft. level the lower series occupies an estimated area of 30 sq. miles.

The coal contents are estimated as follow:

Coal above 4,000 ft. . . .	4,252,000,000	metric tons.
Coal below 4,000 ft . . .	1,334,000,000	,, ,,

Fife and Clackmannan [No. 3 on Map].—As already mentioned, the Fife field is linked beneath the Firth of Forth with the Lothian fields, and at its western end is, with the Clackmannan field, continuous beneath the River Forth and its estuary with those of Lanark and Linlithgow. The area of coal-bearing measures in Fife, inclusive of a strip in Kinross, is 148 sq. miles, and that in Clackmannan, inclusive of a small area in Perthshire, is 41 sq. miles. In Fife, 20 seams over 1 ft. in thickness occur in the upper coal series and aggregate 65 ft., while in Clackmannan the number of seams decreases to

17 and the thickness to 50 ft. The lower series in Fife contains 39½ ft. of coal and locally, around Lochgelly, a considerably greater thickness, but in Clackmannan the aggregate decreases to 23 ft.

The "actual reserve" of coal is about 6,180 million tons, and in Fife and Kinross the "probable reserve" between 4,000 and 6,000 ft. is 351 million.

Linlithgowshire [No. 4 on Map]. The coal bearing area of this county is 61 sq. miles. The Coal-Measures contain 4 seams aggregating 9 to 10 ft. and the Carboniferous Limestone 4 to 6 seams, with 12½ ft. of coal, which however, split up and thin out westward. The famous Boghead mineral occurred in the west of this district. The estimated coal reserve is 680 million tons.

Stirling and Dumbarton [No. 5 on Map]. Coal extends over 193 sq. miles of these counties, but in Dumbartonshire is found only in the lower series. Where developed the Coal-Measures have 34 ft. of coal in 13 seams and the Limestone from 17 to 25½ ft. of coal in from 10 to 15 seams respectively. The coal reserve is 1,920 million tons.

Lanarkshire [No. 6 on Map]. In the great industrial county coal is found over an area of 275 sq. miles. James S. Dixon [16] has stated that the Coal-Measures, which occur over a large area, contain in the Hamilton district 7 seams with an aggregate thickness of 27 ft., and, below these 4 seams with 9 to 10 ft. of coal, while the Limestone series over an area of 235 sq. miles may average 6 ft. of coal in thin seams which thicken eastward in Linlithgowshire between Bathgate and Wilsontown.

In the detached portion of the field to the south around Douglas, 5 seams, aggregating 27½ ft. of coal, are found in a small area of the Coal-Measures, while the Limestone series, which underlies part of the field, contains 50 ft. of coal on the south-western margin and 37 ft. to the north. The blackband ironstone of the lower series, discovered by Mushet early in the nineteenth century, has contributed largely in the past to the prosperity of this county. The coal reserve is estimated at 3,000 million tons.

Renfrewshire [No. 7 on Map].—The area of this coal-field is 73 sq. miles, but the coal reserves only amount to 135 million

tons, contained in 7 seams, aggregating 16½ ft., in the Carboniferous Limestone.

Ayrshire [No. 8 on Map].—Igneous rocks, occurring as erratic lateral intrusions, have destroyed large quantities of valuable coal, particularly in the southern half of the field, and in consequence an estimate of reserves is difficult. J. S. Dixon, in 1904, estimated the available coal as 1,082 million tons, while A. Strahan's estimate of the actual reserve in 1913 was 1,337 million tons distributed over 330 sq. miles.

The Coal-Measures in the northern part of the field contain from 12 to 14 seams with 28 ft. of coal, and round the south-eastern, southern and south-western margin, from 7 to 11 seams with from 26½ to 30 ft. of coal. In the Carboniferous Limestone around Muirkirk, from 10 to 13 seams aggregate from 36 to 54 ft., but in the southern part of Ayrshire the series is poorly developed, and it is estimated that the seams over half the field become so thin and so affected by igneous rock as to be valueless. The blackband ironstone of the lower series occurs at Dalry in the north.

A narrow patch of the Limestone series, some 5 miles long, lying in the Girvan valley, has 6 seams, with a total thickness of 27 ft. of coal.

Dumfriesshire [No. 9 on Map]. Sanquhar Coal Basin. This detached area of Coal-Measures extends for 5 miles, with a width of 3 miles in the Nith valley beside the village of Kirkconnel, and contains 8 seams with 23½ ft. of coal. The Limestone series is absent. At Canonbie, 7 seams, each over 3 ft. thick, and aggregating over 40 ft., have been worked, but never wholly proved at one point. Two groups of seams are assigned to the Coal-Measures, and one to the Limestone series. These coal-bearing measures are overlaid to the south by the barren red sandstones and shales of the Carboniferous system, on which, in turn, Triassic sandstone lies unconformably. It is possible that this field may be the northern limit of the concealed coal-field in the north of Cumberland and the assumed part beneath the Solway Firth. The coal-bearing area of this county is estimated at 20½ sq. miles and the coal reserve, inclusive of the small amount in Argyll, apparently at 667 million tons.

Argyll [No. 10 on Map].—At Campbelltown, on the west coast

of Kintyre, 2 sq. miles on land and half a square mile under the sea are occupied by Carboniferous Limestone, in which 8 seams aggregate 45 ft. of coal. Mining has been carried on here for many years on a moderate scale.

Sutherland [No. 11 on Map]. At Brora on the Dornoch Firth coal of Jurassic age occurs and is probably nearly contemporaneous with the carbonaceous strata of Whitby in Yorkshire [19]. The coal, first worked here in 1598, is of comparatively little value. The estimated quantity is 1 million tons.

IRELAND

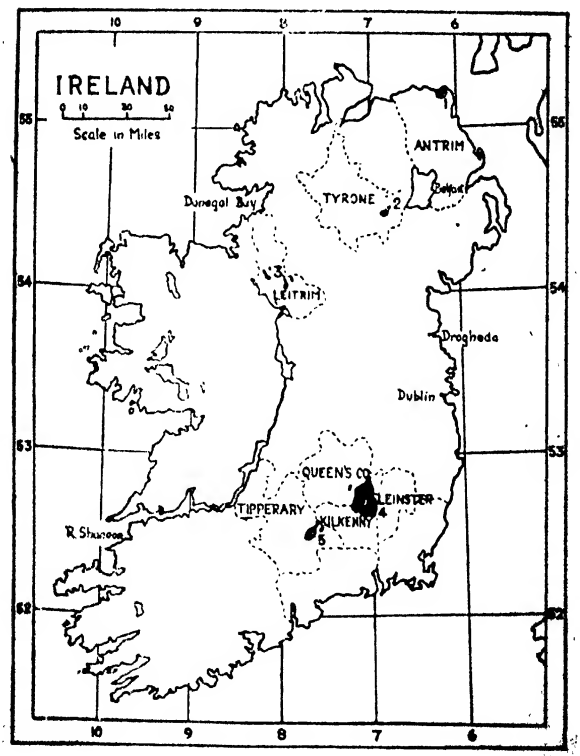
There is evidence that the Carboniferous system extended over the greater part of Ireland, and that the productive Coal-Measures occupied a large area. But denudation in Permian times spared little of the latter, and remnants only of this wealth of fuel exist in small and isolated coal-fields. The coals in the northern half of Ireland are in general bituminous; those in the southern half are semi-bituminous or anthracitic. They are found in seams which, excepting some in the Antrim and Tyrone basins, are extremely thin.

G. A. J. Cole and E. St. J. Lyburn [2 p. 629], estimated the "actual coal reserve" of Ireland to be 180 million tons, and the "probable reserve" to be 110 million tons. Of the "actual reserve," 153 million tons lies in the Leinster coal-field. These resources, though comparatively small and mostly occurring in thin seams, might be more fully utilized were greater local enthusiasm applied to their continued development.

Ballycastle [20]. This field, No. 1 on Map, lies on the north coast of Antrim, and, though now practically abandoned, is of considerable geological interest. The coal-bearing strata are correlated with the Lower Coal and Ironstone series of Scotland, and are in the belt of north-east and south-west folding, which affected the Scottish coal-fields.

The section of strata on Ballycastle Bay includes the upper, or Splint seam, 3 ft. thick; the middle, or Hawksnest seam, 3 ft. thick; and the lower, or Main seam, 4 ft. thick; while on Murlogh Bay, to the east of Fair Head, similar strata, with seams from 2½ to 5 ft. thick, are repeated over a small area. A

few hundred tons only were mined in 1917. The area of the field is 4¼ sq. miles, and if an average thickness of 3 ft. be assumed, the "probable reserve" of coal is 13 million tons.



Tyrone [No. 2 on Map].—At Dungannon, in the southern portion of this coal-field, Lower Coal-Measures outcrop, and they are assumed to underlie an area of 8 sq. miles. Within this area, in the northern part of the field, Middle Coal-Measures

which are found outcropping at Coal Island, are assumed to occupy an unworked area of 1½ sq. miles [21].

The coal-seams occur in descending order as follow [1]:

		Ft.	In.	
Middle Coal-Measures (Coal Island)	Upper Coal	2	2	impure
	Annagher coal	0	0	soft quality
	Bone coal	3	0	
	Shining seam	2	10	
	Brackaville coal	5	0	good quality
	Gortnaskea coal	6	0	cannel 2 ft. 1 coal 4 ft
	Baltiboy coal	3	0	sulphurous
	Derry coal	3	6	good quality
	Yard coal	3	0	good quality
	Creenagh coal	3	0	cannel, 14 in.
Lower Coal-Measures (Dungannon)	Drumglass Main coal (variable)	3 to	4	0
	Lower Monkey coal	1 to	2	0 [10, p. 336]

Considerable faulting is found, particularly in the seams of the Middle Coal-Measures. These seams have been rather extensively worked to a shallow depth, but coal-mining in this field seems to have ceased in 1917.

In 1919 boring was carried out by the Government towards Lough Neagh to test the coal supposed to continue in that direction, but the borehole was stopped before being completed. In the same year a Belfast firm began sinking at Coal Island in order to develop coal mining there.

The estimated "probable reserves" of Tyrone are: Middle series, 43 ft. of coal over 1½ sq. miles, 0·3 million tons; Lower series, 4 ft. of coal over 8 sq. miles, 3·1 million tons.

A small outlier of Coal-Measures at Annaghone, 4 miles to the north of Coal Island, is 1¼ mile long and less than one-fifth of a mile wide. The thick Annagher seam of Coal Island was worked here and is now exhausted, but in the lower seams, if they exist here, there may be a "possible reserve" of 3 million tons.

Lough Allen [No. 3 on Map.—(Arigna; 22]. This coalfield lies in the counties of Sligo, Leitrim and Roscommon, and consists of two areas about two miles to the west of Lough Allen, and a third situated at a similar distance to the east. The seams occur in the Millstone Grit and Lower Coal-Measures, which form the covering rocks of high table-lands about 1,100

[1] For analyses see [23].

to 1,200 ft. above sea-level. The seams are found in descending order as follow:

	Arigna (West of Lough Allen).	Slieve-an-Terin (East of Lough Allen).
Lower Coal-Measures	Upper coal, 1 ft. 8 in. (not always present and not worked)	? Hidden by peat
Millstone Grit	Middle coal, 1 ft 10 in. to 2 ft. 3 in.	1 ft. 0 in. to 1 ft. 7 in.
	Crow coal, 6 in to 1 ft 1 in	2 ft. 6 in. to 4 ft. 0 in. (coal and shale intermixed).

The coal of the middle seam is of good quality and commands a fair price locally, but the thinness of the seam and lack of drainage facilities have in the past impeded development.

The estimate of coal reserve in the two Arigna basins is 5 million tons, and in the Slieve-an-Terin basin 3½ million tons. The production in 1917 was 2,200 tons.

Nodules of carbonate of iron are found in the Shales below the coal-bearing strata, and this ore was formerly smelted on a small scale at Drumahaire in Co. Sligo.

Leinster.—Castlecomer [No. 4 on Map]. This coal-field, which is the largest and most important in Ireland, occupies portions of Kilkenny, Carlow and Queen's counties, and covers 95 sq. miles. It occurs as a synclinal basin rising above the surrounding Carboniferous Limestone. The middle and lower Coal-Measures only are found, and the seams contained are anthracitic. The coals of the middle series are mostly worked out, the only coal left being about 3½ million tons in the Jarrow seam. In the lower series, the second lowest seam, known either as the Upper Towlerton or Skehana or Wolfhill seam, has an average thickness of 20 inches. It is assumed to underlie the whole of the field, and to contain 150 million tons. The output in 1917 from Kilkenny was 61,742 statute tons, and from Queen's County 14,156 tons.

Tipperary.—(Slieveardagh). Tipperary coal-field, known also as Killenaule, lies to the south-west of the Leinster field and contains anthracitic seams, which have been correlated with those of Leinster. The upper Towlerton seam, known here as the Upper Glengoole seam, varies from 18 to 24 inches in thickness, and is estimated to contain 15 million tons. The coal in the limited area occupied by the middle Coal-Measures, may be regarded as exhausted. The output from Tipperary in 1917 was 4,403 statute tons.

Clare, Limerick, and Kerry [No. 5 on Map].—Coal-Measures are found extensively in these counties, and coal has been worked to a small extent. Little, however, seems to be known regarding the coal, except that the seams in general are thin, and that two are reported to be thick, but remote from transport and market. Anthracite has been worked west of Kanturk, to the north of Abbeyfeale, and at Ballaghbehy.

ASIA

British North Borneo

Coal is found in many localities in British North Borneo, but much investigation will be necessary before an estimate of the reserve can be made. The Coal is supposed to be entirely of Tertiary age.

According to T. Posewitz [24], "coal-beds extend along the coast from Sarawak to Brunei. Thence they are continued either along the coast or on the neighbouring islands." They are known to occur at the following places, beginning in the west of the State of Sarawak, and continuing round the coast to the north of the island, and down the eastern coast to St. Lucia Bay:

Near the junction of the Simunjan river with the Sadong; on the river Linga, a tributary of the Batang Lupar; on the rivers Rejang, Mukah, Bintuluh; in the north-east of Sarawak on the Baram river; in the Territory of Brunei in the Limbang river and its tributary the Madalum; near the town of Brunei at Muara or Brooketon, on the island of Labuan; in the territory of the British North Borneo Chartered Co. at Batu-Batu in Brunei Bay, on Gaya island, on the Sequati and Kurina rivers, on the Pankoka river east of Marudu Bay in the extreme north of Borneo, in Sandakan Harbour, and at Silimpopon, 12 miles from the shore of St. Lucia Bay in the south-east of the Territory. Coal also occurs in the interior at a locality south-west of Mt. Kinabalu, and at Penungah on the Kinabatangun river.

In the Muara coal-field there are 5 seams, 28, 26, 29, 5 and 2 ft. thick, the first two being worked. The seams, where explored, dip at an angle varying between 45° and 80°, and, from

the nature of this roof and floor, it has been conjectured that they are inverted, but at a distance of two miles the strata assume a gentle dip, and the seams may here be found in a normal position.

T. Lewis [2/p. 90] gives the following analysis of the 28-ft. seam: Water, 11·48, Vol. matter, 40·24; F.C., 46·70; Ash, 1·58; Sulphur, 0·36; Calories, 6,667. This thick seam is remarkably low in ash, like thick Tertiary coal-seams at Ombilin in the west of Sumatra (27 ft. thick), at Makum in the north-west of Assam (80 ft. thick), and in the Westport-Mokihinui coal-field of New Zealand (high-class coking coal ranging from 4 to 50 ft. thick).

An ultimate analysis of Labuan coal, made by John Percy, is as follows: C, 72·27; H, 5·20; O and N, 14·28; S, 0·30; Ash, 1·85; Hygroscopic moisture, 6·10.

The structure of the Silimpopon coal-field on St. Lucia Bay is believed to be synclinal, and the strata are gently inclined or horizontal. One seam, 5 ft. 10 in. thick, with 4 ft. 8 in. of workable coal, is being mined. An analysis of the dried coal is as follows:

C, 70·04; H, 5·62; O, 8·80; N, 0·85; S, 2·47; Ash, 11·62; Calories, 7,416 [2/p. 92].

It is estimated that this field has an "actual reserve" of 5,600,000 tons, and a "probable reserve" of 70,000,000 tons.

Federated Malay States

The discovery of the Selangor coal-field prior to the war has been a great boon to Federated Malay States. Starting with an output of 11,523 tons in 1915, the collieries turned out 101,846 tons in 1916, 155,279 tons in 1917, 168,740 tons in 1918, and 191,293 tons in 1919. Hydraulic filling of the waste on account of the thickness of the seams is to be adopted.

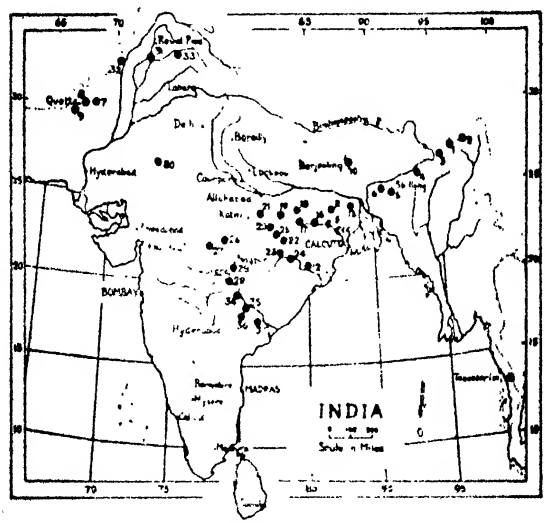
The coal would appear to be a Tertiary lignite. An analysis made at the Imperial Institute gave: Water, 18·23; Volatile, 35·50; Fixed carbon, 41·19; Ash, 5·08; Sulphur, 0·38; Calorific value, 5,466 calories [2/p. 349].

Excellent briquettes have been made in England from this coal [25] [26].

INDIA

The coals of India are found chiefly in the peninsular area and, to a comparatively small extent, in the extra-peninsular hill country of Assam and British Baluchistan, in Sind, Rajputana, Burma, and the Andamans and Nicobars.

The coals of economic value in the peninsular area are of Permo-Carboniferous age, those of the extra-peninsular districts are of Tertiary age, except certain small coal-fields



of Assam, which are of Cretaceous age, and of the Salt Range in the Punjab, which are of Jurassic age. The Jurassic measures of Cutch contain seams of coal which are, however, so far as known, too thin to be of economic value.

Before the more important coal-fields are dealt with in detail, it may be of interest to glance at one or two outstanding features of Indian geology which have a bearing on the subject of the Coal-Measures. For this purpose it is convenient to consider the country as divided into three areas, namely, (*a*)

the peninsular area of the south, (*b*) the mid-north diluvium-covered area of the Indo-Gangetic belt, (*c*) the extra peninsular area to the north, east and west.

The peninsular area has maintained geological stability and its character as a land surface over an immense period of time, from the earliest palæontological record to the present era. The extra-peninsular area, on the other hand, has experienced immense changes in elevation, culminating in Tertiary times in stupendous uplifting from the depths of an ocean bed to the towering heights of the folded Himalayan region. It therefore follows that the geological changes effected over these two areas are of different orders. In the peninsular area the active agencies were sub-aerial, fluviatile and plutonic, and fossil evidence is almost entirely terrestrial and capricious, while in the extra-peninsular areas the changes are largely subaqueous, and the fossil evidence, being marine, is of a more definite and reliable nature. By a correlation of the strata containing these coeval evidences, many of the puzzling problems regarding the age of the terrestrial deposits can be solved.

Not only was India bounded on the north during Permo-Carboniferous times by an immense sea stretching far beyond its borders, and of which the Mediterranean is now a remnant, but it was the northern portion of a land surface connecting it with Central and South Africa, Australia and South America, the whole forming the land surface known to geologists as Gondwanaland. To the existence of this land surface may be traced the marked similarity of the terrestrial fossil remains in the Permo-Carboniferous Coal-Measures of these countries.

The geological sequence of the Gondwana rocks with which the Coal-Measures are associated is as under:

Division.	Series	Stage.	Approximate age.
Lower Gondwana	Panchet		Zechstein
	Damuda	Raniganj Ironstone shales Barakar	Artinskian
	Talchir	Karharbari Boulder-beds	Uralian Muscovian

At the base of the Talchir series there occurs a glacial boulder-bed, known as the Talchir conglomerate, and analogous with glacial boulder-beds in Australia, South Africa, and South America. The Karharbari stage contains coal sparingly. By

some authorities it is considered that this stage, with the Giridih coal-field, should be classified with the Barakar beds.

The Damuda series, if with it be included the doubtful Giridih coal-field, contains all the workable coal-seams of Peninsular India, and over 99 per cent. of the whole available Indian coal. The Barakar and Raniganj stages are the productive measures; the ironstone shales are barren.

A general description of the coal fields of India is given by H. H. Hayden in *The Coal Resources of the World*, 1913, and a detailed description by Ball and Simpson; while a concise summary has been compiled by T. H. D. La Touche [67]. An exhaustive record of analyses of Indian coals by Wyndham R. Dunstan is included in his papers *On Coal Resources of India and their Development* [42].

Output of Indian Coal-fields for Years 1916 and 1917

(In long tons of 2,240 lb.)

	1916		1917	
		Per cent of Indian total		Per cent of Indian total
Bengal, Bihar and Orissa:				
Daltonganj	[illegible]	0·11	79,027	0·44
Giridih	[illegible]	[illegible]	824,007	4·52
Jaintia	[illegible]	0·11	86,804	0·48
Jharia	[illegible]	[illegible]	9,[illegible]88	53·72
Bokaro-Ramgarh	[illegible]	1·14	360,700	1·98
Raniganj	[illegible]	[illegible]	5,376,022	29·52
Sambalpur (Hingir-Rampur)	52,[illegible]	0·30	52,892	0·29
Central India:				
Umaria	200,285	1·16	178,497	1·09
Central Provinces:				
Ballarpur	84,[illegible]	0·49	93,303	0·52
Pench Valley	154,[illegible]	[illegible]	204,562	1·12
Mohpani	48,[illegible]	0·28	71,093	0·39
Hyderabad:				
Singareni	615,290	3·56	680,629	3·74
Assam	[illegible]	1·16	391,480	1·05
Baluchistan	42,[illegible]	0·24	40,785	0·22
N.W. Frontier Province	75,[illegible]	0·43	215	0·29
Punjab	47,[illegible]	[illegible]	49,860	
Rajputana	13,[illegible]	0·08	6,045	0·03
Total	17,294,369	100·0	18,212,918	100·0

NOTE.—In 1918 the output of Indian coal-fields amounted to 20,721,543 long tons, an increase of 14 per cent on that of 1917 (*Rec. Geol. Surv. Ind.*, 50, part 3, 1919, p. 145).

Actual and Probable Reserves of Coal-fields of India

—	Actual Reserve.			Probable Reserve.			Possible Reserve.
	Area.	Class of coal. (see page)	Metric tons.	Area.	Class of coal (see page)	Metric tons.	—
Bengal, Bihar and Orissa :							
Raniganj	—	—	—	400 sq. miles	B_2 and B_3	22,000,000,000	—
Jherria	—	—	—	150 „ „	B_2 and B_3	21,500,000,000	—
Giridih	2,604 sq. miles	B_3	3,000,000				
Daltonganj	1 sq. mile	B_2	10,000,000				
Hutar	—	—	—	20 „ „	B_2	9,000,000	—
Aurunga	—	Low grade	—	—	—	20,000,000	—
North Karampura	—	—	—	250 sq. miles	B_2	8,000,000,000	—
South Karampura	—	—	—	15 „ „	B_2	75,000,000	—
Bokaro	—	—	—	150 „ „	—	1,525,000,000	—
Rajmahal Hills	—	—	—	70 „ „	C	210,000,000	—
Central India :							
Rewah State (Umaria, etc.)	—	—	—	2,000 „ „	B_3	22,057,000,000	—
Central Provinces :							
Sarguja and Chattisgarh	—	—	—	—	—	—	Very large
Mohpani	½ sq. mile	B_3	11,800,000	24 sq. miles	—	58,000,000	—
				50 „ „	—	100,000,000	—
Pench Valley	650 acres	D_1	14,470,000	—	—	—	—
	436 „	D_1	9,400,000	—	—	—	—
				2,870 acres	D_1	64,664,000	Large
Pench River	506 „	D_1	6,170,000	1,402 „	—	31,500,000	—
Central Pench	736 „	D_1	16,000,000	1,012 „	—	16,700,000	—
Pench Cons. Co.'s property	—	—	—	1,981 „	—	24,200,000	Large
Jatcheapa	820 acres	D_1	16,240,000	—	—	—	—
Wainca	—	—	—	3 sq. miles	D_1	60,000,000	—

Wun	—	—	—	80 sq. miles	—	2,130,000,000	—
Wun-Papur	7 sq. miles	D_1	53,000,000	—	—	—	—
Junara Chicholi	5 ,,	D_1	76,000,000	—	—	—	—
Ghugus	—	—	—	3 sq. miles	B_3	45,000,000	—
Ballarpur	2 sq. miles	D_2	31,000,000	—	—	—	—
Pasni and Sasti	1½ ,,	C	30,000,000	—	—	—	—
Singareni	4 ,,	B_3	12,000,000	—	—	—	—
Madavaram	—	—	—	10 sq. miles	—	25,000,000	—
Lingalla	—	—	—	5 ,,	—	8,000,000	—
Assam:							
Namchik	—	—	—	—	—	—	Large
Margherita	549 acres	C	35,000,000	—	—	27,000,000	—
Borhat	—	C	2,500,000	—	—	—	Large
Nazira Bor Jan	—	C	1,500,000	—	—	—	Considerable
Wakting Jan	—	—	—	—	—	—	,,
Daranggiri	20 sq. miles	C	7,000,000	40 sq. miles	C	—	—
Langrin	—	—	—	—	—	—	Large
Cherrapunji	¼ sq. mile	C	1,500,000	—	—	—	—
Latrungso	½ ,,	—	3,000,000	—	—	—	—
Mawsandiam	¼ ,,	—	400,000	—	—	—	—
Mawbelarkar	—	C	3,000,000	—	—	—	—
Lakadong	—	—	—	512 sq. miles	—	350,000	—
Baluchistan:							
Khost (including Shahriz, Harnai, Mach and Zhob)	—	—	—	19 sq. miles	D_2	20,000,000	Considerable
Digari and Sor Range	—	—	—	7 ,,	D_2	25,000,000	Perhaps equal to probable reserve
Burma	—	—	1,000,000	—	—	—	—
Kashmir and Jammu	—	—	—	—	—	—	—
Punjab	—	—	—	—	—	—	—
Rajputana	½ sq. mile	D_2	1,250,000	—	—	—	—

Assam

Coal-Measures of Tertiary and Cretaceous age are found in Assam, the former in the extreme north-east on the north-western front of the Naga, Patkai and Singpho Hills, and the latter more to the south-west in disconnected areas in the Jaintia, Khasi, and Garo Hills, where, however, Tertiary coal also occurs to some extent.

Makum (No. 1 on Map). The Tertiary coal of Upper Assam has attained its greatest development at Makum between the Tirap and Namdang streams, where a seam, ranging from 15 to 80 ft. in thickness and averaging probably 50 ft., is being actively worked by the Assam Railway and Trading Company. Other seams occur, and the aggregate thickness of coal is about 80 ft. The strata dip about 40° to the south-east, that is, towards the hills, and as the outcrops are at several hundred feet above the plains, large quantities of coal can be won by adits. The coal is one of the best in India, and has the following average composition: Carbon, 75·90, Hydrogen, 5·18, Oxygen and Nitrogen, 12·42, Ash, 2·03, Water, 2·15, Sulphur, 2·15; Calories, 7,447.

Interesting accounts of the district are given by H. H. Hayden [49], J. M. Maclaren [74], and G. E. Harris [48] (manager of the collieries). The last named has estimated that down to water-level the total quantity of coal between the Tirap and Namdang streams is 90,000,000 tons. The output in 1918 was 294,484 long tons.

Namchik [No. 2 on Map].—The Coal-Measures extend north-easterly from Makum for a distance of 40 miles, and, on the Namchik river, 30 miles from Makum, a seam is exposed containing 21 ft. 6 in. of excellent coal, with three interbedded clay-bands aggregating 4 ft. 3 in. [79].

Jaipur, Nazira, Janji and Disai [No. 3 on Map].—South-west from Makum coal is found consecutively at Jaipur, Nazira [88], Janji and Disai, a distance of 100 miles. An average of 23 samples of coal from these districts and the Makum field assayed: Hygroscopic Moisture, 5·0, Vol. matter, 34·6; Fixed Carbon, 56·5; Ash, 3·9 [73].

Mikir Hills [No. 4 on Map].—In the Mikir hills, westward from the Disai river, coal occurrences have been reported on by F. H. Smith, Saise, and La Touche at:

Longloi [89]; coal 12 ft. thick and poor in quality;

Dissoma river [85]; two seams of lignite, 3 ft. 10½ in. and 3 ft 3½ in., with 13 per cent. of moisture and 5·8 per cent. of ash;

Nambor [89] and Doigrung rivers [65]; coal valueless on account of the high ash content.

Jaintia and Khasi hills No. 5 on Map] W.S.W. from the Mikir hills there are the Jaintia, Khasi and Garo hills on which Tertiary and Cretaceous coal is found at various points. Oldham [78] reported on a few occurrences, and Ball and Simpson [35/p. 25] refer to the more important localities in short descriptions.

The coal-seams occur over an aggregate area of considerable extent, but in more or less isolated fields from 500 to 5,000 ft. above sea-level. At any one spot there may be two and, occasionally, three seams, which, though sometimes 7 ft. thick, are usually less than 5 ft. The quality of the coal is at times distinctly inferior, through excess of moisture and iron pyrites, but in certain cases is excellent, as for example, at Cherrapunji and Maoflong, where Tertiary coal, ; to 7 ft. thick over a small area, has a composition given as Volatile matter, 37·1; Fixed Carbon, 62·0; Ash, 0·9. The amount of coal available is still undetermined.

Garo Hills [No. 6 on Map]. In the southern portion of the Garo hills Cretaceous coal occurs at Daranggiri on the Sumesari river, and westward near Harigaon. H. B. Medlicott [75] reports that the only field of value is that at Daranggiri, north of the point where the river cuts through the main range at Jankaray village. La Touche [66] mentions 6 seams, of which one, varying from 3½ to 7½ ft. in thickness, is workable. None of the others ever exceeds 1 ft. The seam lies horizontally, is undisturbed by faults, and is mostly above the level of the main streams. The coal is bright black in colour, with a brown streak, contains numerous specks of resin, and burns freely. The average analysis given of two samples is: Moisture, 8·8; Volatile, 36·3; F.C., 49·8; Ash, 5·1. The available coal

is estimated at 76 million tons, but the field cannot be developed till connection with the railway has been effected by means of an aerial ropeway and a branch railway.

Baluchistan

In the arid and mountainous country passed through by the Sind-Pishin railway, via Chapper Rift, coal of Tertiary (Middle Eocene, Laki-division) age is found over a considerable area about 4,000 ft. above sea-level. The seams are numerous, but highly-inclined, and the district is much disturbed by faults. Coal of workable thickness only occurs at one or two places.

Khost Collieries [No. 7 on Map].—The chief of these is alongside of Khost railway station, where mining is systematically carried on by the North-Western Railway. The Khost collieries are, according to Griesbach [45], situated in a wedge of strata let down between parallel faults, but the mining area is free from faults. The dip of the strata is about 50° to the S.W. The principal seam worked is from 22 to 26 in. thick, and assays: Water, 2·29; Vol. matter, 41·51; Fixed Carbon, 46·52; Ash, 9·68. A. Mort, the manager, in an interesting description of these collieries [77], gives the following analysis of the coal:

Carbon	67·69	Calorific value, 6,528 calories.
Hydrogen	5·21	
Sulphur	1·08	
Oxygen	13·48	Fixed carbon and volatile hydrocarbon are approximately equal in amount.
Nitrogen	1·57	
Moisture	2·09	
Ash	5·88	
	100·00	

About 10,000 tons of briquettes per year are made from coal-dust.

Sharigh [No. 7 on Map].—Near the station of this name, 8 miles east by south of Khost, old workings on 2 seams with 16½ in. and 21 in. of coal were reopened in 1910, and in the same year a 32-inch seam was opened up at Harnai, 23 miles east by south of Khost. Coal also occurs, and is worked on a small scale at Digari in the Zharakhu valley, Mach, and the Sor Range [No. 9 on Map]. In 1913, coal was being won from a thin seam a few miles from Quetta [No. 8 on Map] for use in the town. The writer at that time examined an outcrop in the

foothills some 15 miles N.E. of Hindu Bagh, in the Zhob valley. The coal is in very disturbed strata, in which nummulitic limestone occurs, and appeared valueless on account of its shattered condition. The output from Baluchistan (inclusive of Kalat State) in 1918 was 43,125 long tons.

Bengal

Darjeeling (No. 10 on Map). The coal-deposits of Darjeeling are of Damuda age, and may probably be correlated with those of the Aka and Daphla hills north of the Brahmaputra opposite Disai and Janji in Assam (74, 40).

Bose examined a belt of Coal-Measures 2¾ miles long and ¾ mile wide between the Lisu and Komthi rivers in the sub-Himalayan range and 3 or 4 miles from its foot. Severe earth movements have crushed and powdered the coal, and altered it, in places, approximately to anthracite or graphite, but, in general, the coal retains its caking character. All the rocks are usually tilted at an angle of from 45° to nearly vertical. Thick seams are numerous, and Bose estimated that 5½ million tons of coal could be readily won within an area of 100 acres, and that in the square mile examined there might be 20 million tons. Ash varies from 13 to 22 per cent., and a comparison with Raniganj coal is as follows:

	Vol. matter	F.C.	Ash.
Darjeeling, average of 8 samples	22·01	59·56	17·42
Raniganj, average of 31 samples	30·63	53·20	16·17

The powdered character of the coal limits its application to the making of coke, carbonized coal,[1] or briquettes.

Jainti, Sahajori, Kunda Kuanah (54, p. 247). These three small and unimportant coal-fields lie 160 miles N.W. of Calcutta, near the Giridih field, and comprise 11½ sq. miles occupied by Barakar rocks. The seams are few, and none exceeds 3 ft. in thickness. Samples from Sahajori contained from 28 to 37 per cent. of ash.

Giridih (Karharbari) (No. 11 on Map). This small, but valuable coal-field lies 175 miles N.W. of Calcutta. The coal-

[1] A kind of carbonized coal from slack is used by natives in their huts on the Jherria coal-field.

bearing Barakar beds occupy 7 sq. miles, are much faulted, and are subject to igneous intrusions which have destroyed much coal [84/p. 86] [51].

In descending order there are (1) Hill seams, (2) Karharbari seams, and in both groups numerous seams occur. The Hill seams individually have a great thickness, and aggregate from 33 to 96 ft., but the ash varies from 13 to 55 per cent. The two lowest seams have been extensively mined. In the Karharbari group the so-called "Lower" seam is the most important. It exists over the whole area, is uniformly of good quality, and has seldom less than 12 ft. and on average 15 ft. of excellent coal—described by Saise in 1894 as the finest steam coal in India. In this respect some of the finer coals now developed in the Raniganj and Jheriia basins are certainly equal to it.

It assays: Vol. matter, 24·42; Fixed C., 66·84; Ash, 9·15. The average calorific value is about 6,873 calories [42/p. 393].

The available coal in the field was estimated by Saise as 113 million tons. The output in 1918 was 5,302,295 tons.

Bihar and Orissa

Talchir [No. 12 on Map]. The Talchir coal-field lies in the valley of the Brahmini, a river north of, and parallel with the Mahanadi. It is 220 miles W.S.W. of Calcutta and 110 miles due west of the mouth of the Brahmini. The coal, on account of an excessive amount of ash, is of little economic value [36] [27].

Rajmahal Hills [No. 13 on Map].—The centre of this locality is about 100 miles north by west of Calcutta. Barakar beds are exposed in the west of the hills, and occupy an area of 70 sq. miles [28]. They also extend into the hills beneath the younger sedimentary beds and trap-flows to a distance which must be conjectural; no instance was observed by Ball of the coal being affected by the overlying basaltic trap. The seams are thin, an average of 5 ft. of workable coal being a probable maximum, and in the exposed area contain a total of 210 million tons of coal. Some 100,000 tons have probably been won from this district, much of it very inferior quality. Samples from this

teen localities assay: Fixed Carbon, 42·13; Vol. matter, 39·50; Ash, 16·37.

The coal-fields about to be described, from Raniganj to Karanpura South, are situated in the Damuda valley, and occur in order from east to west. These and a few adjoining basins contain the great reserve of Indian coal.

Raniganj [37] (No. 14 on Map). This is the largest coal-field being worked in India and is the most adjacent to Calcutta, from which it is distant about 115 miles in a direct north-west direction. The area of coal bearing rocks of Barakar and Raniganj horizons is 400 sq. miles; 350 to 440, and an extensive addition eastward under the Ganges alluvium and the higher beds of the series is indicated by recent boring. The field is bounded on all sides, except the eastern, by the metamorphic basement rocks. It has sunk on the southern and south-western edge along a line of fault, so that the measures have in general a tilt to the south at angles of from 5° to 20°. Numerous faults and dykes are met with in the workings here and there, and small areas of coal have been destroyed by igneous intrusions. Ball and Simpson state that the coal deteriorates in passing from west to east, and that as a general rule no *first-class* coal exists east of a fault running between Raniganj and Egarah.

In the upper or Raniganj horizon 10 seams, with an aggregate thickness of 110 ft., have been worked; 37, and in the Barakar horizon four seams with a total of 60 ft., while many other seams are known to occur within the field. Assuming an average thickness of 50 ft. of *workable* coal, the total quantity of coal would be over 21,000 million tons. Of this, 500 million tons are *first-class* coal, 350 million are *medium* quality coal, the balance being *second-class* coal.

Saise [83] gives the following summarized analyses:

Series.	Moisture	Vol. matter	Fixed Carbon	Ash.	Number samples
Raniganj (Upper seam) .	6·09*	42·30	40·28	11·43	7
do. (do) .	6·64	42·06	40·25	21·05	4
do. (Lower seams) .	3·79	41·76	52·94	11·51	20
do. (do.) .	3·74	41·26	46·41	18·59	8
Barakar	1·12	25·13	59·75	14·00	2
do.	1·00	26·80	52·69	19·51	5

* *Note.*—It is probable that the moisture is sometimes as high as 9·0.—J. H. R.

As Saise points out, there is a progressive dehydration as the seams deepen in the series.[1]

The coal is bituminous, but only of good coking quality in certain seams. Ball and Simpson state that the best coal is in the lower seams of the Raniganj series, although their quotation of tests published by F. C. Hughes [52] indicates a higher calorific value in coal from the Barakar series.

Jherria [No. 15 on Map].—Jherria coal-field, 16 miles west of Raniganj, ranks in importance second only to Raniganj, while in production it now ranks first. It occupies a basin semi-circular in shape, and has an area of 150 sq. miles. The strata in general dip at about 10° from all sides towards the centre of the basin, but more steeply on the southern margin, where, as in Raniganj, but to a less depth, the measures have been let down by faulting into the metamorphic rocks, and preserved from complete denudation.

Unlike Raniganj, the lower or Barakar series of Jherria field contains the best and thickest seams, and Ward [90], who re-surveyed the field, gives a total of 17 seams exceeding 5 ft. in thickness in this group. Another seam, No. 18, was discovered by Stonier in 1902, and several more have since been discovered. In the upper, or Raniganj series, two workable seams are said to occur near the base. A recent description of the field has been given by G. H. Greenwell [44]. Numerous igneous dykes have destroyed large quantities of coal, and from their effect at unproved depths an estimate of the coal reserves must be conjectural.

Difficulty in mining and serious loss of coal have been experienced through the great thickness and the liability to spontaneous combustion of some of the best seams; for instance, 1 seam is 100 ft. thick. It is inclined at 45°, and sections of it are being worked. It is evident that methods of working used in thin seams require modification in seams of such mammoth dimensions, and it is gratifying that sand-filling or "flushing" of the goaf is now in operation at one or two collieries in this field.

The average composition of the coal varies greatly, but that

[1] It may also be noted that variations in the ash contents affect only the amount of fixed carbon, and not the volatile matter.—J. H. R.

of seams Nos. 12, 13 and 17 (Barakar series) given by Ward is: Vol. matter, 29·14; Fixed Carbon, 59·30; Ash, 11·56. Holland [50] gives 15 as the average ash percentage of these seams.[1] Moisture is about 1 per cent. Nine samples of coke gave 0·66 per cent. of sulphur and 0·17 per cent. of phosphorus. The better coals of the Jherria field have an evaporative power of about 12·5 [42/p. 303]. The output in 1918 amounted to 10,951,060 tons.

The coal reserves of Jherria have been estimated at: *First-class* coal 500 million tons, and *second class* 21,000 million tons.

Bokaro Jherria [5]; No. 16 on Map. This field, which is now found to be a continuation of the Jherria field, stretches westward about 10 miles, and has an average width of 5½ miles and an area of 220 sq. miles. Coal seams are very numerous, but of workable thickness only in the Barakar series, which, in the eastern ten miles of the field has several thick seams of good quality. One in particular the lowest, is 88 ft. thick, and has a moderate dip. Elsewhere, the beds are much faulted and generally steeply-inclined, while, throughout the field, igneous intrusions have destroyed much coal. The southern boundary fault of the preceding fields is also more or less in evidence here. The probable coal reserves of the field are 1,500 million tons. Active mining is now being carried out, chiefly by the East Indian and Bengal Nagpur Railways, and the production in 1918 was 541,077 long tons [59].

Ramgarh [29] (No. 16 on Map). This field lies on the Damuda river some 5 miles south of Bokaro, and has an area of 40 sq. miles. In the eastern portion the seams are generally thick, but of variable quality; to the west the coal is better, but crushed, and the strata are faulted. Ball [34], on the scanty data available, estimated 5 million tons as a safe figure for the coal reserves.

Karanpura [No. 16 on Map]. This is the most westerly of the six coal-fields, beginning with Raniganj, which stretch from east to west in the Damuda valley [54/p. 285; 35/p. 57]. It

[1] It is noticeable that the percentage of fixed carbon plus ash is, with a few exceptions, always close to the constant 78·5. The percentage of volatile matter is not affected by the proportion of ash, a fact also particularly noticeable in Saise's analyses of coal from the Raniganj field—J. H. R.

lies immediately to the west of Bokaro and Ramgarh fields, and is divided by a strip of basement gneiss into North Karanpura and South Karanpura areas. Hughes computes in the northern rea 250 sq. miles, with 35 ft. of coal and a content of 8,750 nillion tons, and in the southern area, say, 15 sq. miles, with 0 ft. of coal, representing 75 million tons. The actual quantity f coal is probably much greater.

A few occurrences only of igneous intrusion are observable, nd the fault common to the southern margin of the fields to the east, is here almost the only one indicated. The better seams assay: Volatile, 27·0; F.C., 64·5; Ash, 8·5 [35/p. 57].

Chope [30] and *Itkuri* [55] These two small fields lie north of Kalanpura, and contain coal only fit for use in local brick and lime kilns.

Aurunga [31] [No. 17 on Map].- Six miles west of Kalanpura field; area, 58¼ sq. miles. Seams in the Barakar beds are numerous and sometimes very thick, but only three merit attention. The quality of the coal is inferior, as indicated in the following analysis. Moisture, 6·7; Volatile, 29·2; F.C., 36·5; Ash, 27·5 [31/p. 111].

Hutar [31] [No. 17 on Map]. This field lies on the Koel river, about 12 miles west of Aurunga. Barakar beds cover 57 sq. miles, and contain three workable seams measuring 8 ft., 8 ft., and 13 ft. 8 in., but the extent of these is unproved, and an estimate of quantity cannot be made. A composite assay of eight samples was: Moisture, 5·95; Vol. matter, 28·00; Fixed Carbon, 55·35; Ash, 10·70.

Daltonganj [64] [No. 18 on Map]. - This field is situated on the Koel and Amanat rivers from 16 to 20 miles north of the Hutar field. Coal-bearing Barakar beds are found over 30 sq. miles, and boring made by the Public Works Department in 1891 indicates the existence of two seams over most of this area. But these appear to be of economic value only over 1 sq. mile to the east of Rajhara, where it is estimated that there may be 9,000,000 tons of coal. The analyses usually quoted, being from borehole samples made at that date, are open to question, and, since the average annual output from 1909 to 1916 was 80,000 tons, it may be assumed that the coal is of a useful quality.

Central India

Rewah State

Singrauli [No. 19 on Map].—This is the most northern field in the province. Coal was discovered near Kota by Wroughton in 1840, and was being mined in 1855–7 when Roberts and Smith reported on the field. Smith records a 6 ft. seam 6 miles S.W. of Kota, and a 21 ft. seam about 12 miles further west. Oldham's party surveyed the Rewah district in 1895–6, but Griesbach's Notes [40] on the work give no further useful detail than that "there is here a large coal-field with an abundant supply of coal." The surveyed area of Coal-Measures is said to be 200 sq. miles, what area may be coal-bearing was evidently unknown.

It is interesting to note that in the Talchir horizon striated and polished boulders were observed in the glacial beds, and that in the Damuda measures *Glossopteris* attached to the rootstock *Vertebraria* were found.

Sohagpur [No. 20 on Map].—This field has an area of 1,600 sq. miles. It is characterized by the great lateral extent of the coal-seams, their nearly horizontal position at a shallow depth, their small number and moderate thickness. A detailed account of the field by Hughes [56 p. 177] was published in 1885. The most important seam is described as about 5 ft. thick, and was traced from near Bargaon for 10 miles along its outcrop. Reader, in 1899–1900, found it ranging from 4 ft. 8 in. to 13½ ft. thick between Bageha stream and the Son river. Seams of moderate thickness and fair quality are exposed at Nandnah, Bhalmuri and Sabo. Average analysis: Water, 3·7; Vol. matter, 26·0, F.C., 58, Ash, 12·3. No estimate of the coal reserves has been made.

Six miles westward from the most westerly point of this field, coal-bearing Barakar rocks are again exposed in the Johilla field; 23 miles W.N.W. from the same point is Umaria field, with Korar field 4 miles to the north. To judge from Hughes's map, these are extensions and the western limits of Sohagpur field, separated from the latter by intervening country covered by more recent measures. But Hughes does not express an

opinion on this point. Metamorphism of sandstone by intrusions of trap to rock, indistinguishable in hand specimens from ordinary granite, was observed west of the town of Sohagpur.

Johilla [56].—Area, 11½ sq. miles; two seams, respectively 17 ft. and 6 ft. Analysis: Vol. matter, 34·85; F.C., 54·43; Ash, 10·72. Hughes hazards the estimate that within a depth of 500 ft. there are at least 100 million tons of coal. The mining rights are under the direction of the Rewah Durbar [35/p. 78].

Umaria [No. 21 on Map].—Area of exposed Coal-Measures, 6 sq. miles; six seams, four being worked; thickness from 3 ft. to 12 ft. [35/p. 76]. Coal, non-coking; analysis: Moisture, 5·46; Vol. matter, 19·71, F.C., 66·71, Ash, 8·12 (Hughes). Coal reserves to 500 ft. deep, 55 million tons. Since 1900 the working of the coal-field has been under the direction of the Rewah Durbar. In 1918 the output of the State was 199,975 tons [35/p. 78].

Korar [56] [No. 21 on Map].—Situation, 4 miles north of Umaria field, of which it is probably a continuation; area, 9½ sq. miles; four seams proved at a shallow depth, varying in thickness from 4 to 8 ft. No reliable analysis is available, and the possible quantity of coal cannot be estimated.

Central Provinces

Extending south-westerly from the western end of the *Raniganj-Hutar* line of coal-fields there are Ramkola-Tatapani, Bisrampur, Jhilmilli, Lakhanpur, Rampur (Sarguja), and Korba coal-fields. The coal occurs in Barakar beds.

Sarguja State

Ramkola-Tatapani [47] [No. 22 on Map].—Area is 100 sq. miles, with probable considerable extension under upper Gondwana rocks. The measures are much faulted and intruded with trap as sheets and dykes. There are several seams, but few of economic thickness or quality. The best, on the Morne river, can be traced for more than a mile, and varies from 3 ft. 6 in. to 7 ft. 9 in. The quantity and quality of the coal generally are unproved, and the isolation of the field precludes early development.

Bisrampur [32] [No. 22 on Map].—Situation, south of Ramkola and difficult of access; area, 400 sq. miles. The strata are mostly horizontal and free from faults. The seams are numerous, but thin, so far as known, and boring is necessary. Analyses given by Ball are:

Seams.	Moisture.	Volatile.	F.C.	Ash.
Rehr and Pasang rivers . .	(5·5)	37·6	57·0	5·4
Mahan and Masan rivers . .	(4·0)	32·3	48·1	19·6

Jhilmilli State

Jhilmilli [56/p. 69] [No. 22 on Map].—Lies due west of Bisrampur field; area, 41 sq. miles. Ball's description, quoted by Hughes, is based on a hurried examination, and only indicates the existence of coal. A thin seam is said to occur in the Talchir beds [55/p. 2].

Sarguja and Bilaspur

Lakhampur [55/p. 81] [No. 23 on Map]. Is south of Bisrampur, partly in Sarguja and partly in Bilaspur; area, according to Lala Hira Lal [70], is 340 sq. miles. Coal from several outcrops from 3 to 9 ft. thick, contains from 5 to 28 per cent. of ash, and is non-coking. A typical sample had 13 per cent. ash.

Rampur (Sarguja) [No. 23 on Map]. Lies south of Lakhanpur; estimated area, 70 sq. miles. Ball described the field in 1882 [33], and Lala Hira Lal [71] later mentioned numerous outcrops from 2 to 7 ft. thick. The ash content is from 12 to 25 per cent., but that of 1 seam of 5 ft., a mile east of Bhahue, is reported as less than 4 per cent.

The following small coal-fields adjoining the foregoing have been described by Lala Hira Lal in MS. reports 1885–9, but are apparently of little value. They are Bansar, Panchbhaini, Sendurgar, Damhamunda.

Chattisgarh Division

Korba [No. 24 on Map].—In Chattisgarh Division, south of Rampur field; area about 300 sq. miles [68/p. 95]. A seam 40 ft. thick, near Korba, was described by Blanford [38].

Boring by King in 1886 showed this seam to be valueless, and did not disclose any large quantity of good coal elsewhere, but King states that Hira Lal found one seam, 5 ft. 3 in. thick, with 7 per cent. of ash, on Aharan river, near Sumedha. The Barakar coal-bearing beds, either exposed or covered by younger rocks, extend in this division to the south-east through the Mand river and Rampur (Ball's Raigarh-Hingir field) fields to the Ib river, a total distance of 100 miles. Mand river coal is very inferior.

Rampur (Raigarh-Hingir) [No. 24 on Map].—This field lies partly in Bihar and Orissa, and has an area of 300 or 400 sq. miles. Boring, conducted by King [62] between 1884 and 1886, proved numerous seams, with 30 per cent. or more of ash. Subsequent boring, advised by Reader [81] in 1900, disclosed workable coal, and mining was begun in 1909. The output in 1918 is given as 51,036 tons.

Korea State

Lying between Jhilmilli on the east and Sohagpur on the west, this hilly and rather inaccessible state has been partially examined by Hughes [56/p. 202] and by Fermor [43]. It possesses four separate coal areas, viz. Senhat, Jhagrakhand, Kurasia and Koreagarh.

Sanhat [No. 25 on Map].—This is the most northern and the largest field, 50 miles long from east to west and 8 to 12 miles wide, comprising 330 sq. miles. It is traversed by the headwaters of the Hasdo (Hestho) river. Two seams of value occur, with an average dip of 10° to 12° to the north. The lower is valueless in its western half, but from 4 to 9 ft. thick over a length of 16 miles in its eastern portion, and has the following variable composition: Moisture, 3·18 to 8·20; Volatile, 26·90 to 29·50; F.C., 37·60 to 50·46; Ash, 15·38 to 32·24.

The upper seam is of value only towards the west, and varies from 3 ft. 6 in. to 9 ft. 9 in. in thickness. It assays: Moisture, 3·10 to 5·71; Volatile, 21·06 to 26·33; F.C., 36·82 to 50·19; Ash, 22·98 to 36·68.

Kurasia [No. 25 on Map].—This field lies 5 miles south of Sanhat field; its area is 48 sq. miles, and is divided into the

Kurasia and the Chirmiri portions. In the former, six coal horizons were noted, of which the third, in descending order, shows a seam from 1 ft. to 8½ ft. thick, and possibly averaging 5 ft. over 4 sq. miles. It assays: Moisture, 7·52 to 10·74; Volatile, 30·12 to 31·32; F.C., 46·96 to 49·88; Ash, 9·32 to 13·82.

The fourth horizon at one locality has a seam 11½ ft. thick, and the fifth at another locality has a seam 8 ft. thick. The quality is good, and further investigation is desirable.

In Chirmiri area, seven seams, aggregating 36 ft. of coal in a total thickness of 48 ft., are found at Karai Khoh waterfall. The two lowest seams are each 12 ft. thick, and are separated by 1 ft. of shale. The mean composition is: Moisture, 7·7; Volatile, 29·1, F.C., 51·2, Ash, 12·0. The coal thins out rapidly in all directions, but possibly from 1 to 2 sq. miles may carry coal at least 10 ft. thick, yielding about 11 million tons per square mile.

Jhakra-khand [No. 25 on Map]. Coal 5 ft. thick, and of good quality, is said to occur here [56 p. 108].

Koreagarh [No. 25 on Map]. In Koreagarh, Fermor reports "three exposures, with thicknesses varying from 3 to 5 ft., with intervening bands of stone." The description is obscure.

Satpura

The Satpura basin begins about 60 miles W.S.W. of Jabalpur, and lies south of the Nerbada river. Its estimated minimum area is 2,000 sq. miles, but much of the surface is occupied by rocks more recent than the Coal-Measures, which are definitely proved only at intervals. The chief localities are: Mohpani, Shapur (Betul) and Chhindwara.

Mohpani [No. 26 on Map].—Situation, on the north of the Satpura hill ranges; area of exposed Coal-Measures (Barakar), over 1 sq. mile, but south, east and west these measures continue under younger rocks, and to the north beneath Nerbada alluvium. Ball and Simpson [35/p. 92] refer to four seams ranging from 5 to 25 ft. in thickness; on the other hand, La Touche [68/p. 100] mentions four seams ranging from 2½ to 10 ft., and that the most recent exploration proves "an aggregate thickness of 40 ft. over a considerable area." The estimated workable

coal is 8 million tons which further exploration may considerably increase. Recent analyses give: Moisture, 2·52; Vol. matter, 24·26; F.C., 48·71; Ash, 24·01; Sulphur, 0·50. The G.I.P. Railway exploits the field, and in 1918 produced 78,792 tons.

Shapur [No. 27 on Map].—Situation, 60 miles S.W. of Mohpani, on the Tawa river, between Betul and Hoshangabad; area of exposed Barakar measures, 26 sq. miles. H. B. Medlicott in 1875 [76] recorded a number of fairly promising outcrops, but subsequent boring failed to prove any coal of value [35/p. 93].

Chhindwara (Pench Valley) [No. 27 on Map].—This field occurs as a narrow belt lying east and west on the south of Satpura range on the Tawa, Kanhan and Pench rivers, and covers 100 sq. miles. E. J. Jones [60] recognized five distinct coal areas:

1. *Sirgora*; area, 1 sq. mile; one seam proved, 5 ft. thick, assaying: Moisture and Vol. matter, 28·0; F.C., 61·6; Ash, 10·4.

2. *Barkoi* (Pench Valley); area, 7·4 sq. miles; three workable seams, 7½ ft., 5 ft., and 5 ft.; estimated available coal, 100 million tons; composition: Water and Vol. matter, 22·8; F.C., 53·5; Ash, 23·6 [35/p. 95].

3. *Hingladeri*; area, 2·8 sq. miles; one seam from 2 to 5 ft. thick, exposed and said to be of good quality.

4. *Kanhan*; area, 12 sq. miles; several seams, from 5 to 10 ft. thick, exposed; one at Datha assayed: Water, 5·34; Vol. matter, 28·36; F.C., 48·58. Ash, 17·72, but other samples gave up to 46 per cent. of ash.

5. *Tawa*; area, 70 sq. miles, partly in the Betul district; outcrops are few, but a seam of 7 ft. and another of 11 ft. occur; two samples assayed: Water, 3·05; Vol. matter, 26·20; F.C., 51·90; Ash, 18·85.

The output from the Pench Valley in 1918 was 267,303 tons.

Chanda District, Wardha Valley

The coal-fields of this district, with the exception of Bangar, lie along the valley of the Wardha river for a distance of 70 miles. They consist of Banda, Warora, Ghugus, Wun with Junara and Chicholi, Sasti and Ballarpar, and Paoni [57]. The district is

characterized by great thickness of coal contained practically in one seam.

Bandar [No. 28 on Map].—Situation, 50 miles S. by E. of Nagpur and 30 miles N.E. of Warora; area of coal-bearing Barakar rocks, 6 sq. miles. Three seams occur, with a maximum total thickness of 38 ft. (Ball and Simpson, p. 90). Boring proved an aggregate thickness of 17 ft. over 1 sq. mile [68/p. 96]. Quality is similar to that of Warora.

Warora [No. 29 on Map].—Situation in Wardha valley, 62 miles south of Nagpur; area, 3 sq. miles with 20 million tons of available coal [57]. One 12 ft. and one 15 ft. seam occur. The coal is friable and inferior to that of Raniganj, containing an excess of moisture and sulphur. Fires from spontaneous combustion are said to have caused the loss of 70 per cent. of the coal [41], and pumping charges were heavy. A serious subsidence in 1906 finally led to the closing of the collieries and a transference of operations to Ballarpur [68/p. 96]. About 3 million tons of coal in all have been produced. Two analyses gave: Moisture, 11·72, Vol., 29·33; F.C., 43·80; Sulphur, 1·55; Ash, 13·60.

Ghugus [No. 29 on Map].—S. of Warora; area, 3 sq. miles; seam, 32 ft. thick, depth to top 74 ft.; Composition: Vol. matter, 33·40, F.C., 45·61; Ash, 20·99. Estimated available coal, 90 million tons [57/p. 1]. A little coal was won here in the early seventies.

Wun.—N.W. Ghugus; area of probably productive coal lands, according to Ball and Simpson [35, p. 89], is 80 sq. miles, containing 2,100 million tons; quantity proved between Wun and Papur, 105 million tons; coal thickness, 15 ft. Also quantity proved between Junara and Chicholi, 150 million tons; coal thickness, 30 ft. Composition: Vol. matter, 19·4; F.C., 63·9; Ash, 16·7.

Ballarpur.—7 miles S.S.E. of Chandha; chiefly on the Hyderabad side of the Wardha river; area proved by boring, 14 sq. miles; thickness of workable coal, 20 ft. On stoppage of Warora (see above) a colliery was started; production in 1917, 86,261 tons. Composition: Water, 12·30; Vol. matter, 31·09; F.C., 45·34; Ash, 11·27 (La Touche) [68/p. 96].

Rajputana

Bikaner [No. 30 on Map].—The only known coal of Rajputana is of lower Tertiary age (Eocene), and was discovered during the sinking of a well, 13 miles S.W. of Palana [68/p. 111]. It lies immediately beneath nummulitic limestone at a depth of 212 ft., is persistent over a considerable area, and varies in thickness from 3 to 30 ft. The coal is a resinous, woody lignite of a brown-black colour, and is liable to rapid disintegration and spontaneous combustion. The moisture can be reduced by a special process of briquetting described by W. H. Phillips [80], as indicated by the following analyses:

	Raw Coal.	Briquette No. 1.	Briquette No. 2.
Moisture	22·90	14·84	9·32
Volatile	35·30	40·94	44·36
F.C.	38·10	38·78	38·80
Ash	3·58	5·74	7·52

The apparent alteration in the ratio of volatile matter to fixed carbon is noticeable. Further interesting notes on the subject of briquetting are given by E. H. Robertson [82], and reference to the treatment of lignite is made under "Canada," p. 103.

The output declined from 45,078 tons in 1904 to 11,334 in 1918. As the measures are overlaid by a sandy plain the coal reserves can be determined only by boring.

Punjab

The coal deposits of this province are unfortunately few and far between, of scant development, and of generally poor quality. The need of coal in the arid and treeless districts where they are found, alone gives them the little importance they possess. The coal of economic value is chiefly of Tertiary age (Eocene, Laki division); a little Jurassic coal is found. It occurs in the following localities:

Jhelum (Salt Range) [No. 31 on Map].—At Bhaganwala [69], at the eastern end of the range, a colliery worked by the North-Western Railway Co., produced 13,145 tons, but, in 1899–1900, owing to the inferior quality of the coal, operations were discontinued; at Dandot [35/p. 110], 19 miles west of

Bhaganwala, and at Pidh [68/p. 111], 3 miles from Dandot, the same company worked mines from 1884 to 1911. The output declined from 92,000 tons in 1897 to 30,000 tons in 1911. Local contractors in 1916 produced 44,944 tons. The coal is a friable, much-jointed lignite.

Shahpur (Salt Range) [No. 31 on Map].—Jhakar Kot [68/p. 111]. The coal here, as in Jhelum, occurs in shales and sandstones, beneath nummulitic (Eocene) limestone, as lenticular beds separated laterally by wide intervals of barren ground. The average thickness of seam is about 3 ft.

Mianwali [No. 32 on Map]. Isa Khal, west of the Indus. Simpson [86] surveyed this field in 1904, and described three areas:

(*a*) *Kalabagh:* Jurassic measures, with 3 seams possibly containing 80,000 tons.

(*b*) *Kuch:* Jurassic measures, containing about 14,000 tons in two seams, too thin to be profitably worked.

(*c*) *Malla Khel:* Tertiary measures, along the Maidan range, containing possibly 500,000 tons above free drainage level.

The coal production of the Punjab in 1918 was 50,658 tons, of which the bulk was from the Jhelum area.

North-West Frontier Province [68/p. 107]

Indications of coal occur in Hazara (Dore River), also near Kohat, in the Sherani Hills, and in Wazaristan, but no coal of value has been found.

Kashmir

The Jammu coal-fields [No. 33 on Map], in the south of Kashmir, lie within 35 miles of the Punjab frontier. They are of Tertiary age, and were examined in 1904 by Simpson [87], who has described the areas known as the Ladda, Sangar Marg, Mehowgala, Siro Valley, Kalakot and Lodhra coal-fields.

Of these fields, Mehowgala, Kalakot and Lodhra are valueless. Siro Valley has coal of fair quality in two seams from 2½ ft. to 4 ft. thick, lying at an easy angle, containing possibly 250,000 tons. Ladda and Sangar Marg are portions of the one field separated by the Chenab river, but, according to Simpson,

the only workable part is in Ladda, between Ladda and the Anji river, a length of 10 miles. Here the single seam, varying in thickness from nothing to 20 ft., and averaging 31 inches, may contain 1¾ million tons, with a possible addition of about 2 million tons.

Analyses of Ladda coal, with a few exceptions, show an abnormal percentage of ash, and frequently over 5 per cent. of sulphur. On account of these features Simpson suggests that washing and briquetting the coal would be necessary.

Hyderabad

Pranhita-Godavari Valley [61]

Ball and Simpson [35/p. 95] and La Touche [68/p. 103] describe eleven small detached coal-bearing areas of Barakar rocks in this province. King's memoir, though thirty-eight years old, best describes the geological features of the district. Beginning at Ballarpur of the Wardha River field and going southward we find the following coal areas: Sasti, Antargoan, Aksapur, Tandur, Chinur, Kamaram, Bandalla, Singareni, Kunnegiri, Lingalla and Madavaram.

(*a*) *Sasti* [No. 34 on Map].—A continuation westward of the Ballarpur field of the Wardha Valley already referred to [35/p. 90]. One seam of 50 ft., composed partly of good coal and proved over an area of 1½ sq. miles, may contain 30 million tons.

(*b*) *Antargoan* [No. 34 on Map], south of Lathi Ghat on Wardha river, contains a seam, with 5 ft. 3 in. of coal, which, at the outcrop, has 20 per cent. of ash and 8·7 of moisture.

(*c*) *Aksapur* [No. 34 on Map], a small exposure of Barakar rocks on the Jangaon river, in which coal has not been found [61/p. 180].

(*d*) *Tandur* [No. 34 on Map].—A seam, 15 ft. thick at Khairgura, but of varying thickness down to 9 ft., was traced by Hughes for 7 miles to the Guloti river. Analysis: Vol. matter 42·2; F.C., 45·6; Ash, 12·2 (Water, 9·4).

(*e*) *Chinur* [No. 34 on Map] consists of a narrow belt of Barakar beds, without visible outcrops of coal, between Chinur and

Sandrapali villages. But water-borne lumps of coal are found in the Godavari river near the mouth of its tributary, the Sandrapali stream [58].

(*f*) *Kamaram* [No. 35 on Map], an area of 156 acres, with a 6 ft. and a 9 ft. seam of good coal, estimated to contain 130,000 tons.

(*g*) *Bandalla* (Allapalli) [No. 35 on Map]. On the Kumersani river, an outcrop of coal, 6 ft. thick, is referred to by King, and Blanford, in 1871, noted fragments of coal 22 miles further down the river at Allapalli, probably derived from an outcrop of the seam.

(*h*) *Singareni* [No. 36 on Map].—Four seams in descending order, measuring, respectively, 30 to 40 ft., 6½ ft., 4½ ft., and 3½ to 7 ft., were proved by boring. The thick seam consists of alternating bands of coal and shale, and parts are said to be workable, but the fourth seam, known as the King seam, only has been worked. In the latter, Sarse estimated a quantity of 36 million tons [84/p. 53]. J. P. Kirkup has described the colliery operations [63].

The output in 1918 was 659,129 long tons. Analyses are:

	Moisture	Volatile	F C	Ash.
Thick seam . . .	—	31·50	53·50	12·00
King's seam . . .	7·60	25·25	56·50	10·65

(*i*) *Kunnegiri* [No. 35 on Map].—A small patch of Barakar rocks without visible coal.

(*j*) *Lingalla* [No. 37 on Map].—Blanford [39] records the finding of a 5-ft. seam in the bed of the Godavari river, and two thin seams in the banks. Boring here and on the western side of the river appear to have proved no coal of value, but in 1891 a seam, with 4½ ft. of coal, is said to have been struck at a depth of 11 ft. on the British side, and 70 tons of good coal were raised.

(*k*) *Madavaram* [No. 37 on Map].—A small field lying on both sides of the Godavari below Bhadrachellam. On the Hyderabad side boring disclosed 3 seams, of which one at 247 ft. was 4 ft. thick, and another at 272 ft. was 6 ft. In 1897 a 51-foot seam of fine quality was reported to be struck on the British side, and to contain about 24 million tons of coal. Ten sq. miles are supposed to be coal-bearing [35/p. 96].

Madras

Godavari Valley

Kamthi rocks occur extensively in this valley, but the underlying Barakar beds, with coal outcrops, are found in the Madras Presidency only at Beddadanol and Madavaram (or Damercherla). To what extent the Coal-Measures may continue beneath the Kamthi strata is quite unknown.

Beddadanol [No. 37 on Map].- Four seams of coal and coaly shale passed through in boring are so high in ash as to be quite valueless.

Madavaram. (See Hyderabad, p. 65.)

Burma

Thin lenticular strings of poor coal, referred to the Carboniferous period, occur in the Tennasserim valley ; with this exception, the coals of Burma are of Tertiary age. These Tertiary coals are lignitic in character, more or less hydrous, and poor in quality. With a few exceptions the seams are thin, and the quantity of available coal is small. These features limit its application strictly to local use.[1] References to the individual occurrences are made by Ball and Simpson [35] and La Touche [67], who append a bibliography of the various reports on the fields.

AFRICA

Kenia, Tanganyika Territory and Somaliland (see p. 158)

Nyasaland

The coal of Nyasaland, which was discovered during the course of a mineral survey carried out in co-operation with the Imperial Institute, occurs in rocks of the Karroo formation distinguished by examples of *Glossopteris* and other plants characteristic of that formation [92]. These rocks are found

[1] But in Hsipau State of Northern Shan States, considerable deposits of Tertiary coal occur. At a point 150 miles east of Mandalay and 50 miles west of the Chinese border a coal-seam, 24 ft. thick without parting, is being opened out at Namma by the Burma Corporation. The seam dips at 45° at the outcrop, but gradually assumes a less angle as it is followed down. It yields: Moisture, 14; Vol. matter, 33; Fixed C., 48; Ash, 5.

in the north of the territory, and in the extreme south-west between the Shire river and the Portuguese border.

In the northern district the Mount Waller area has outcrops of a 2-ft. and a 5-ft. seam yielding excellent caking coal. Analyses made at the Imperial Institute showed: Vol. mat., 23·80 to 28·11; F.C., 56·92 to 66·73; Mois., 1·01 to 1·30; Ash, 8·15 to 17·98; S., 0·59 to 0·64; Cal., 6,814 to 7,982. It is sufficient to say at present that the coals of Nyasaland, with the exception of that of Mount Waller, are varied in quality and generally very high in ash, and that the seams, so far as known, are few and comparatively thin [91].

Rhodesia

The coal of Rhodesia occurs in the Karroo formation, chiefly in the basin of the Zambesi river, and to a small extent in the valley of the Limpopo, near Tuli, and of the Sabi to the south-east of Victoria.

Very little exploratory work has yet been carried out, and active mining has hitherto been confined to the Wankie coalfield at a point on the railway 212 miles north-west of Bulawayo and 68 miles south-east of Victoria Falls.

But the needs of Mashonaland must before long be satisfied by the extension of the railway system to the north-west of Salisbury into the coal-bearing ground in that direction.

The coal-seams worked at Wankie colliery range from 6 to 12½ ft. in thickness, tending to thicken towards the west, and it is stated that 4 miles west of the colliery the seam was found to be 28 ft. thick. To the north-west the Coal-Measures are thrown down by the N.E.–S.W. Deka fault to a depth estimated by G. W. Lamplugh to be not less than 2,000 ft., and are hidden beneath the basalts over which the Zambesi plunges at the Victoria Falls. An analysis of Wankie coal is as follows: Moisture, 0·71; Vol., 21·51, F.C., 64·11; Ash, 11·05; Sulphur, 2·62. Evaporative power is about 13.

H. B. Maufe [103A] estimates the coal reserves to be:

Actual Reserve	about	420 million tons
Probable Reserve	,,	550 ,, ,,
Total	,,	970 ,, ,,

Union of South Africa

The coals of South Africa occur in the Karroo System, which comprises rocks that are regarded as ranging in age from Upper Carboniferous to Jurassic. The following sequence represents the complete development of the series and the beds, but it is doubtful if they have been deposited in their entirety in any one spot:

Karroo System

Series.	Beds.	Type Fossils.	Period.
Stormberg	Drakensburg Volcanics		Jurassic
	Cave Sandstone	Dicynosaurs	
	Red Beds	Dicynosaurs	
	Molteno Beds	Thinnfeldia	Rhætic *
Beaufort	Upper (Burghersdorp Beds)	Cynognathus	Triassic
	Middle	Lystrosaurus	Upper Permian
	Lower	Pareiasaurus	
Ecca	Upper	Glossopteris plants	Lower Permian
	Middle "Coal Measures"		
	Lower (Pietermaritzburg Shales)	Archæosuchus	
Dwyka	Upper Shales	Mesosaurus †	Upper Carboniferous
	Glacial Conglomerate	Gangamopteris	
	Lower Shales	Phyllotheca	

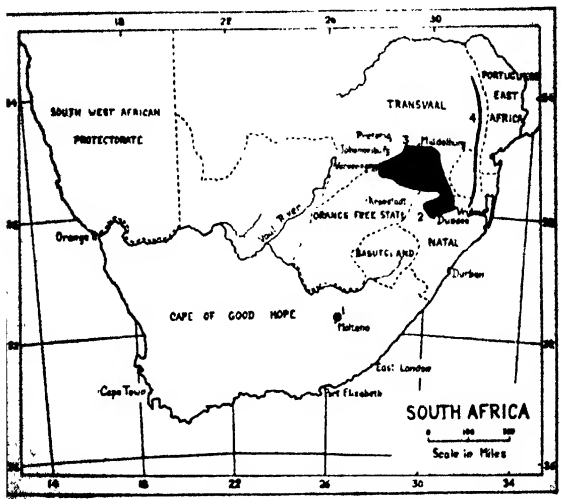
* Some geologists include Rhætic in the Triassic, others in the Jurassic.
† In Brazil *Mesosaurus* occurs above *Glossopteris*.

There has been much diversity of opinion in regard to the separation of the Ecca from the Dwyka Series, but the table may be taken as fairly representing the result of most recent research. There are admitted difficulties in correlating the South Africa series with those of Europe, and the measures classified as Upper Carboniferous [102/p. 236] and Permian share with their equivalents in Australia, India and South America, the uncertainty that has led to the use of the term "Permo-Carboniferous" in reference to them.

The Karroo formation is most fully developed in Cape Province, where the maximum aggregate thickness is not less than 19,000 ft. [102/p. 167], including the volcanic beds. There is a continuous thinning out of the component formations in passing northward and eastward from Cape Province and Natal towards the central portions of the Transvaal, where in the Witbank coal-field the average thickness, exclusive of the glacial conglomerate [99/p. 22] is only about 200 ft., and immediately east of Johannesburg even less.

For a clear conception of the Karroo formation in the Transvaal it is essential to keep this point in mind [101].

A remarkable feature of the system is the Dwyka or Glacial conglomerate, the product of a period of extreme cold. It stretches over immense areas of South Africa, either as the surface rock or overlaid by younger members of the system, two-thirds of Cape Province, large portions of the Orange Free State, the Transvaal and Natal, and a small portion of



Southern Rhodesia being occupied by rocks of the Karroo system.

The only workable coal of Cape Province is found in a clearly defined position, that is, in the Molteno beds of the Stormberg series, and is referred to Rhætic age. Thin and unworkable seams also occur in the Lower beds of the Beaufort Series.

The coals of the more northern regions in Natal, Zululand, the Orange Free State and the Transvaal occupy a more debatable horizon. They have been variously referred to the Storm-

berg, the Beaufort, the Ecca and the Dwyka Series. But the recent researches of Du Toit [94] and others in tracing the formations from their points of fullest development in Cape Province, northward through Natal, leave little doubt that they belong to the Middle beds of the Ecca Series, with the exception of certain occurrences of outlying districts where coal of the Lower beds of the Beaufort Series is developed.

Cape of Good Hope

The coal-seams are found in the Molteno-beds [No. 1 on Map] of the Stormberg district, about 130 miles N.N.W. from East London [102/p. 464] [96]. Three workable seams occur, the lowest being the *Indwe seam*, the second, about 80 ft. higher, the *Guba seam*, and the third, 300 ft. above the Indwe seam, the *Molteno seam*. The layers of coal in any seam seldom exceed 12 inches in thickness and alternate with bands of black shale. At Molteno, for instance, a 6 to 7-ft. seam has about 4 ft. of coal. The seams occur more or less as detatched areas, between which the coal merges into shale, or has been removed by contemporaneous erosion. Rogers and Du Toit, and Schwarz [103] adduce the presence of this shaly admixture as evidence that the vegetable matter was transported from a distance, but whether correct or not, the inference is difficult to reconcile with the evidence of "drift" origin in the case of the singularly pure coal of the Buller coal-field in New Zealand.

Numerous intrusive dykes and sheets of dolerite have frequently produced a coking effect on the coal. This and the high percentage of ash are shown in the official analysis quoted by Rogers and Du Toit, as under:

	Molteno	Cyfergat.	Indwe.	Bamboes Mts.	Matatiele.	Cala.
Moisture . .	1·13	2·24	17·34	1·45	1·37	1·10
Vol. matter . .	10·31	21·25	—	19·16	24·68	9·00
Fixed Carbon . .	60·89	51·04	61·80	54·92	47·53	68·31
Ash . . .	28·80	23·80	21·53	23·90	25·10	19·70
Sulphur . .	0·76	1·48	—	0·93	1·33	0·79
	101·89	99·87	100·67	100·36	100·01	100·90

The amounts sold in 1916, 1917, and 1918 were, respectively, 41,752, 8,300 and 4,654 tons (2,000 lb.). In spite of the

nferior quality, Cape Province coal, through absence of competition, commanded, in 1917, 14/4·05*d.* per ton at the pithead, as against 4/9·32 for Transvaal coal. It is interesting to note that the output per person at work in the Transvaal coal-mine is 6·5 times that in the Cape Province mines, a fact chiefly, if not entirely, due to a difference in the physical conditions of the seams, such as thickness, hardness and intermixture of shale or stone bands.

Coal has been found in the Prince Albert district. A sample examined at the Imperial Institute consisted of a friable anthracite containing: Mois., 2·05; Vol., 8·16; F.C., 88·56; Ash, 1·23; S., 0·33; Cal., 8,277

Natal

The chief coal-mining of Natal has for many years centred in the Newcastle and Dundee districts [No. 2 on Map] of Klip River county, in the north-western corner of the colony, but in the last few years operations have extended eastward to the Vryheid district, and even to the coastal coal-field of Somkele, between St. Lucia Bay and the Umfolosi river. The Coal-Measures of these areas may be regarded as the southern and eastern extensions in more or less detached groups of the Coal-Measures occupying extensive areas in the south-eastern Transvaal and the north of the Orange Free State. The Somkele field would appear to be the southern end of a narrow and remarkable belt of Coal-Measures, which dips eastward beneath the igneous rocks of the Lebombo Mountains, and stretches due north for a distance of 350 miles, through Swaziland and Komati Poort to the Shingwidsi river in the north-eastern Transvaal. It has been shown that the Coal-Measures of Zululand are traceable right up to the border of the Vryheid district, and that the relation of the Vryheid beds to the Newcastle and Dundee series is simple [92/p. 54].

Intrusive sheets of igneous rock are characteristic of the Natal Coal-Measures, and have frequently induced an anthracitic nature in the coal. But the coal mined is the best in South Africa. It is an excellent steam coal, and much of it yields

a good coke, but it is frequently high in sulphur. The following are analyses of typical coals:

Colliery.	Moisture.	Vol. matter.	Fixed Carbon.	Ash.	Sulphur.
Dundee . .	—	16·63	70·53	8·66	4·18
Navigation .	0·53	15·17	71·59	11·41	1·30

The coal of the Somkele field is distinctly anthracitic in character.

Transvaal

The coal-measures occupy extensive, though not altogether continuous, areas in the south and south-east of the Transvaal [No. 3 on Map]. Coal-mining has been chiefly carried on at Brakpan and Springs on the East Rand, Vereeniging on the Vaal river, and in the Witbank-Middelburg district; but mines have also in recent years been opened up on Grootvlei, south-east of Heidelberg, and at Breyton in the Ermelo-Carolina district of the eastern Transvaal. Of these, the Witbank, with the immediately-surrounding district, is at present the largest producer.

Transvaal High-veld Coal-fields.—In the Witbank-Middelburg coal-field the Coal-Measures are, at certain points, separated from the underlying Dwyka conglomerate, with its uneven surface contour, by a considerable thickness of shales, sandstones, and redistributed conglomerate, while in the Brakpan and Vereeniging fields they lie almost on the Dwyka.

Although the Coal Measures in this field varied greatly in thickness through the irregularity of the surface upon which they were laid down, they were apparently continuous, but denudation has reduced this thickness and even, in places, entirely removed the measures, till, in certain cases, isolated areas only remain. The following thicknesses of the coal-measures above the glacial conglomerate have been observed here and at other parts of the country:

Witbank-Middelburg, Maximum 450 ft. . .	average	200	ft.
Brakpan, East Rand	,,	130	,,
Springs, East Rand	,,	208	,,
East of Springs, on Wilge River . . .	,,	500	,,
Viljoen's Drift, Vaal River, Orange Free State .	,,	446	,,
Komati Poort, Lebombo belt . . .	,,	3,200	,,
Swaziland, Lebombo belt	,,	4,000	,,

A marked feature of Coal-Measures of the Middelburg district

nd to a certain degree of the whole Transvaal, is the rapid ariation in the thickness and character of all the constituent eds, particularly the lower beds, a condition due to the strong urrents, which laid down the generally coarse-grained sedi- ients. It can, however, scarcely be doubted that intermittent eriods of quiescence occurred to admit either of the growth *n situ* or of the drifting of vegetable matter to a thickness hich, in the case of the 20 ft. "Main Seam," may have mounted to 250 ft. Though the coal seams share to a onsiderable extent in the variability of the measures, the ssumption of long periods of quiet and stability and a partial, f not entire, "growth *in situ*" origin, is supported by the per- istence of a 12-inch seam of bright coal over a distance of) miles, and of an 18-inch layer of gas-coal at the base of the 'Main Seam" over a still greater distance.

But even in the quiescent periods, incursions of somewhat nuddy water must have occurred with considerable frequency ver the wide areas of accumulating vegetable matter. This is videnced by the layers of muddy matter, either as numerous ninute films, or as occasional bands of shale several inches thick nterlaminated with the otherwise pure coal. Mellor [99/p. 37], n his admirable memoir on the Transvaal Coal-Measures, traces the high percentage of ash in Transvaal coal to this cause.

The following seams, in descending order, are usually found in the Witbank area, except where they have been removed by denudation:

	Thickness.	Intervening Strata	Character.
No. 5 Seam	0½ ft.		Formerly worked at Landau Colliery.
		30 ft	
No. 4 Seam	2½ „		Upper half impure; lower half fair.
		20 „	
No. 3 Seam	1 „		Exceptionally bright.
		30 „	
No. 2 ("Main") Seam . .	10 „		The chief seam.
		7 „	
No. 1 Seam	6 „		Frequent dirt bands.

The "Main Seam" is universally worked and in a typical section consists from the bottom upwards of 15 in. of a somewhat cannel-like "gas-coal," 3½ ft. of bright "smithy coal," 2 ft. of generally impure "holing-coal," often referred to erroneously as a "splinty-coal," and 10 to 12 ft. of semi-bitu-

minous coal composed of alternating layers of more or less bright and dull coal, in which the broader dull bands tend, in certain areas, to become stony and render the upper part of the seam unmarketable for general purposes. No. 4 seam is, in its upper half, much interlaminated with shale bands, but the lower half is of fair quality, and improves from east to west.

The Witbank coal maintains its quality for some distance along the 50 miles of railway connecting its south-westward with the Brakpan-Springs district of the East Rand, but an increase in the percentage of ash gradually supervenes, till at Brakpan the increase becomes pronounced. Otherwise, the general character of the coal persists. At Belfast, 50 miles east of Witbank, on the railway to Delagoa Bay, and almost on the edge of the "High Veld" plateau, a 22-ft. seam of strong, hard, but somewhat inferior coal has been worked to some extent. This seam, 15 miles north of Belfast, is exposed without a sign of deterioration, and is quarried for use by the farmers. That a portion of the seam here was at one time on fire is apparent from the baked and clinkered shales overlying it. Coal of excellent quality occurs in the Ermelo-Carolina district.

Analyses of Transvaal Coals [99/p. 55] (*High Veld*)

	Moisture	Vol. matter.	Fixed Carbon.	Ash.	Sulphur.	Evap. Power.
Witbank District:						
"Main Seam" average over lower 12 ft.	2·22	25·83	57·19	14·76	0·53	12·07
T. and D.B. Colliery "Main Seam" average	1·05	21·93	60·60	14·83	1·59	11·24
E. Rand District:						
Brakpan Colliery	4·50	21·76	52·50	21·50	2·00	9·30
Apex Colliery	5·40	24·47	51·50	17·20	1·37	10·00
Gt. Eastern Colliery	3·12	24·94	54·33	16·27	1·45	—
Heidelberg District:						
Grootvlei Colliery	5·32	21·92	59·46	12·34	0·98	10·70
Vereeniging:						
Central Colliery	5·67	23·40	50·94	18·25	1·94	9·70

Lebombo Belt [No. 4 on Map].—It remains only to notice briefly the long narrow belt of coal-measures already referred to on the "Low Veld" immediately west of the Lebombo Range, and the equivalent "High Veld" formation of the

Springbok Flats, near Pienaar's River station, on the Pretoria-Pietersberg railway.

It is a reasonable assumption that these coal-measures, with probably the overlying amygdaloidal basalt, stretched more or less horizontally, with possibly unbroken continuity, from a line at least as far west as the Springbok Flats to an unknown distance eastward in that portion of Gondwanaland now submerged beneath the Indian Ocean. Anderson [93] in Zululand, Garrard [95/p. 75] in Swaziland, and Kynaston [97] in the Transvaal have traced the continuity of the Lebombo coal-belt, with its dip oceanward beneath the Lebombo Range. Kynaston concludes that the coal-measures at Komati Poort were laid down unconformably on the Older Granite and the Barberton Beds, and that the relative position of these formations is not due to faulting.

In looking at the subject broadly, one is forced to the view that the section, as now seen, from the eastern edge of the "High Veld" plateau to the shores of the Indian Ocean, is due to the great and widespread subsidence eastward, resulting in the flexed, possibly, to some extent faulted, and generally rugged slope, connecting the "Low Veld" with the "High Veld," and that the emergence of the pre-Karroo formations was a natural sequence of rapid denudation of the Karroo formation, with the overlying basalt, from the sloping area, a denudation from which the Lebombo coal-belt has been protected through its lower altitude and by the overlying basalt and the capping of resistent rhyolite.

Mellor [100] [99/p. 17], who mapped the coal-measures of the Springbok Flats area, and Kynaston [98] have shown the similarity of certain beds in this area to beds above the coal-bearing beds at Komati Poort. And the interesting point is made that these, the "Bushveld Sandstones" and the underlying reddish and purplish clays, are the equivalents of the "Cave Sandstones" and the "Red Beds" of the Stormberg Series of Cape Province. It may be noted that this relation may be extended northward into Rhodesia, where the "Forest Sandstones," with their Deinosaurian remains and capping of basalt, are the equivalents of the Bushveld or Cave Sandstone Series and overlying volcanic rocks.

In order to appreciate the position of the "Coal-Measures" of Natal, the Orange Free State, and the Transvaal in the Karroo system, it is necessary to keep clearly in mind the gradual thinning out of the various members of this system in passing northward. Du Toit [94] points out that the Molteno Beds, 2,000 ft. thick between Glen Grey and Elliott in Cape Province, die out below Mont-aux-Sources, and thence, northward, "*are absent, and the succeeding Red Beds come to rest directly upon the Upper Beaufort Beds.*" Further, the presence of *Glossopteris* in the northern Coal-Measures is recorded by Molengraaff and Draper. The correlation, therefore, of these coals with those of Molteno is excluded.

Du Toit also traces the gradual thinning out of the Lower Ecca Beds from the south of Natal northward, till at Ermelo, in the eastern Transvaal and beyond, they disappear, and the Middle Ecca Beds, with the included Coal-Measures, "come to rest either upon the glacial (Dwyka) conglomerate or directly upon one of the older rock systems." He thus definitely refers these "Coal-Measures" to the Middle Ecca Beds, which, he states, "correspond with a high degree of probability with the extreme base of the Permian of Europe," e.g. with the lowest portion of the "Rothliegende." It has, however, to be noted that the Coal-Measures of the Lebombo belt include representatives, both of the Ecca and the Beaufort Series.

Much of the coal at Komati Poort and in Swaziland is anthracitic; at St. Lucia Bay most of it is distinctly so, a feature which has hitherto impeded development of the field. Garrard [95/p. 79] records the interesting fact that the seams in the upper part of the series are in general anthracitic and in the lower semi-bituminous, but advances no theory to account for the difference. Kynaston was inclined to ascribe the anthracitic character of the coal to the prevalence of intrusive sheets and dykes, and to the pressure which must have been exerted by the vast pile of the Volcanic Series.

The Lebombo Coal-Measures are intruded by many igneous dykes and sheets or sills. In the absence of sufficient data it is impossible to determine what influence, whether purely local or widespread, these intrusions had in rendering the upper coals anthracitic, while the lower coals remained little, if at all,

Analysis of Zululand and Lebombo Coals [95/p. 78]

	Zululand.				Komati Poort				Swan Coal Mine.						
	I.	II.	III.	IV	V.	VI	VII.	VIII.	IX	X	XI	XII.	XIII.	XIV.	XV.
	Ntambanana	St Lucia outcrop 5 miles N.W. of III. 10 ft Weathered	Zulu Land Colls portion seam 4 ft level 5 ft	Outcrop Crocodile River		Farley Iniff			Top 6 ft 1 ft in of seam	Middle of seam	B.H. 8 ft 10 in Leevy	B.H. 10 ft in Leevy	B.H. 9 ft 6 in. Leevy.	Shaft B at outcrop 2 ft. 6 in.	B.H. 2. 4 ft. 6 in.
					A	B	C	D	After exposure in dumps for 2 years						
Moisture	0·80	15·35	2·23	0·40	0·60	0·80	0·50	0·50	3·20	1·85	0·68	0·53	0·69	3·50	0·42
Volatile Matter	18·20	20·14	6·87	14·00	4·60	1·00	1·40	1·40	3·80	0·50	18·05	6·85	6·27	16·00	11·58
Fixed Carbon	69·50	41·17	88·20	57·81	64·06	77·70	62·10	71·54	81·50	82·40	71·05	83·11	81·27	72·74	79·40
Ash	13·50	22·44	12·80	13·81	24·84	21·70	35·00	26·56	8·54	5·61	8·45	9·00	11·32	7·76	8·60
Sulphur	0·53	0·73	0·45	Trace	1·30	0·80	0·45	0·50	0·56	0·54	0·45	0·51	0·45	0·71	0·52
Spec. Grav.	1·41	1·60	1·49	—	1·65	1·55	1·58	1·72	1·52	1·40	—	—	—	—	—
Evap. Power	—	—	11·85	—	11·22	11·22	9·58	10·78	13·56	14·54	12·10	11·30	11·10	11·75	13·00

Close to top of coal-measures: III, V, VI, VII, VIII, devolatilized.
Above base of coal-measures: IX, X, XII, XIII, XV, anthracitic.
Near base of coal-measures: I, II, IV, XI, XIV, semi-bituminous.

affected. As regards static pressure, this would be expected to affect the lower more than the upper seams.

In this connection it appears to the writer that another possible factor may be noted. A great thickness of molten matter, amounting at Komati Poort to 6,000 ft., exclusive of the enormous thickness of rhyolite, has first and last flowed over the surface of the Coal-Measures, with its associated coal-seams, and it is difficult to imagine that a considerable amount of heat was not thereby imparted to these Coal-Measures, *possibly sufficient to devolatilize or drive off a portion of the volatile matter from the upper coals.*

The table on page 77 indicates the graduation in character of the Lebombo coals according to their depth in the series.

Coal Production in the Union of South Africa

—	1917			1918.		
	Tons sold (2,000 lb.)	Value per ton at pit's mouth		Tons sold (2,000 lb.).	Value per ton at pit's mouth	
		s.	d.		s.	d.
Cape Province	8,300	14	4·05	4,654	15	3·89
Natal	2,800,296	10	1·76	2,007,133	10	5·10
Orange Free State	813,005	5	1·86	826,577	5	6·70
Transvaal	6,641,229	4	0·32	6,438,961	5	0·84
Total	10,382,920			9,877,323		

The value of the coal at the "pit's mouth" for the five years ending 1917 was, after India, the lowest of any country, and almost exactly half that of the United Kingdom. The comparative value per ton of 2,240 lb. in various countries (1915) is shown in the appended list. The present price of coal is as a result of the war greatly in excess of these figures:

	s.	d.		s.	d.
France	15	7	Japan	6	7
United Kingdom	11	6	U.S.A.	6	1
Germany	10	5	S. Africa	5	10
Australia	7	5	India	4	8

Although the coal has been and must always remain of vital importance to the gold-mining industry, its very abundance

has hitherto induced an attitude of indifference as to the question of possible coal reserves. Consequently, the limits, thickness and variations in quality of the workable seams are still only partially known, although these coal-fields present less difficulty in this respect than almost any others of like extent.

The Coal Reserves, as roughly estimated, are given in the Annual Report for 1911, Part III, *Geol. Surv., S. Africa*, and are as follow:

	Square miles.	Tons.
Transvaal	5,000, average thickness 6 ft	36,000,000,000
Natal	1,000, " " 7 "	9,400,000,000
Zululand	1,250, " " 4 "	6,000,000,000
Orange Free State, Cape Province, Basutoland, Swaziland	Impossible to make even a rough estimate, but the total resources will probably be not less than 1,000 sq. miles, with an average thickness of 4 ft.	4,800,000,000
	Total	55,200,000,000

The present methods of exploitation admit of the utilization of about 55 per cent. of the total coal available. The quality of the coal is extremely variable. The percentage of ash varies from 6 per cent. to 30 per cent., but, in most of the coal actually used, the variation is from 10 to 15 per cent.

If the estimate of the percentage of coal recovered, viz. 55 per cent. only, be correct, methods will doubtless in time be formulated to lessen the lamentable waste, as has been done by some of the progressive mining men of India. Coal-mining in Sumatra is an excellent example of what can be done in this direction.

Southern Nigeria

From 1903 to 1913 a Mineral Survey, conducted in association with the Imperial Institute, was made in Southern Nigeria [105]. Large deposits of lignite or brown coal were found on both sides of the river Niger, near Asaba (*Bull. Imp. Ins.*, 10, 1912, p. 435). Later, in 1909, the large coal-field named the Udi-Okwoga after the native villages at its known southern and northern limits was discovered. The area of this coal-field, so far as known, is about 1,800 sq. miles, and the best-known part is now connected by railway with Port Harcourt. The coal occurs in Cretaceous beds, occupying a plateau which

in the north rises to 2,000 ft. and has a gradual slope to the west. The eastern escarpment exhibits outcrops of coal.

Udi coal is described as sub-bituminous, and is dull-black in appearance. It ignites readily, burns with a bright, steady flame, with little smoke, and without caking or decrepitation:

Analysis (*Imperial Institute*)

	Moisture	Vol.	F.C.	Ash.	S.	Calories.
Udi, 5 ft. seam . . .	5·62	38·18	48·41	7·79	0·76	6,969
Okwoga, 3 ft. 11 in. seam .	11·50	34·96	39·49	14·05	0·73	5,494

In the vicinity of Udi, 4 seams reach a thickness of over 2 ft. Further north a seam 5 ft. thick is exposed on the Azata river. In the Okwoga district similar seams are found of a quality slightly lower in calorific value on the whole.

Udi colliery [104], 151 miles north of Port Harcourt, began operations in 1915, and produced in 1918 148,214 tons. The Iva Colliery, now being developed, promises to be the most important producer.

Details regarding the distribution and analysis of the coal of this field will be found in the *Imperial Institute Bulletin* [104] and *Reports on the Mineral Survey* [105].

NORTH AMERICA

CANADA

In Canada, a country of vast area and with large coal deposits only slightly developed, accurate knowledge of the total coal resources must be necessarily very incomplete, but recent investigations of a detailed character have thrown much light on the subject. The most recent important publications are *An Investigation of the Coals of Canada, with Reference to their Economic Qualities*, 1912, by J. B. Porter, R. J. Durley, and others [116] [111], and *The Coal Fields and Coal Resources of Canada* [2], contributed by D. B. Dowling to the *Coal Resources of the World*, 1913. The details in the following pages are drawn chiefly from these publications, and to some extent from F. W. Gray's *Coal Fields of Eastern Canada* [113].

Canada's Principal Coal-fields

These fields are grouped roughly, with their reserves, in Table I below, into four great divisions, the first three of which are at present of economic importance. Their coal contents have been estimated on the basis of coal already explored with some measure of accuracy [112].

Table I

(1) *The Atlantic Provinces.*—Nova Scotia and New Brunswick:

	Tons
Bituminous Coal	3,500,000,000

(2) *The Central Plains and the Eastern Rocky Mountains:* Manitoba, Saskatchewan, Alberta, British Columbia:

	Tons
Anthracite	500,000,000
Bituminous coal	30,000,000,000
Sub-bituminous and lignite	100,000,000,000

(3) *The Pacific Coast and the Western Mountains:* British Columbia and the Yukon.

	Tons
Anthracite	61,000,000
Bituminous	40,000,000,000
Lignite	500,000,000

(4) *Northern Canada—Mackenzie Basin:*

	Tons
Lignite only	300,000,000

The foregoing table indicates broadly the distribution and character of the coal.

Table II gives the geographical positions and geological ages of the coal-fields.

Table II

Provinces and Coal-fields.	Centre of Field Latitude.	Centre of Field Longitude	Geological Age.
Nova Scotia:			Carboniferous
Sydney field	46° 10′	60° 10′	
Inverness field	46° 10′	61° 30′	
Pictou field	45° 35′	62° 35′	
Cumberland field	45° 40′	64° 20′	
New Brunswick:			Carboniferous
Grand Lake field	46° 05′	66° 00′	
Manitoba:			Tertiary
Turtle Mountain field	49° 00′	100° 00′	

Table II (contd.)

Provinces and Coal-fields.	Centre of Field. Latitude.	Longitude.	Geological Age.
Saskatchewan :			Cretaceous
Estevan or Souris field	49° 05′	103° 00′	
Alberta :			Cretaceous
Belly River field	49° 40′	112° 40′	
Frank-Blairmore field	49° 35′	114° 25′	
Cascade field	51° 12′	115° 30′	
Edmonton field	53° 50′	113° 30′	
British Columbia :			Cretaceous
Crow's-nest field	49° 30′	114° 55′	
Nicola Valley field	50° 20′	120° 30′	
Telkwa Valley field	54° 30′	127° 10′	
Nanaimo field, V.I.	49° 10′	123° 55′	
Comox field, V.I.	50° 00′	125° 00′	
Suquash field	50° 37′	127° 15′	
Graham Island, Q.C.I.	53° 10′	132° 00′	
Yukon Territory :			
Tantalus field	62° 10′	136° 10′	Jura-Cretaceous
Yukon River field	64° 30′	140° 00′	Tertiary
Northern-Mackenzie Basin			Tertiary
Northern Islands			Carboniferous

Age of Coal Deposits

Broadly speaking, the coals of the east, in the Atlantic provinces, are of Carboniferous age, and those of the Central districts and the Pacific Coast are of Cretaceous age. Coal of lower Tertiary age is found in Alberta and Saskatchewan, and Tertiary lignite and sub-bituminous coals, in small areas, occur in British Columbia, Yukon and the Northern Islands. Cannel coal of reputed Lower Carboniferous or Devonian age is found in the Northern Islands, and thin, unimportant coal-seams occur beneath the Carboniferous limestone in Nova Scotia.

Distribution

Important fields of excellent bituminous coal occur on the Atlantic and Pacific seaboards, and are extensively mined and used for general purposes, but the great reserves of bituminous and sub-bituminous coals in Canada are in the interior fields of Alberta and British Columbia, where, particularly in Alberta, coals of a wide range of character are found, from lignite, occurring chiefly on the plains, to bituminous coal and anthracite in the main uplift of the Rocky Mountains.

Coal Resources of Canada

Table III (after D. B. Dowling [2/p. 441])

Group I

ncluding seams of 1 ft. or over, to a depth of 4,000 ft.

District.	Actual Reserve (Calculation based on actual thickness and extent).			Probable Reserves (Approximate estimate).		
	Area Square miles	Class of coal *	Metric tons	Area Square miles.	Class of coal *	Metric tons.
Nova Scotia . .	174·31	P_2	2,137,736,000	27·78	B_2	4,871,817,000
	—	C	50,415,000		C	20,000,000
New Brunswick .	—			121·0	B_2	151,000,000
Ontario . .	—			10·0	D_2	25,000,000
Manitoba . .	—			48·0	D_2	160,000,000
Saskatchewan .	306·0	D_2	2,412,000,000	113·0	D_2	57,400,000,000
		D_2	—		D_2	20,450,000,000
		D_1	52,800,000,000		D_1	464,821,000,000
Alberta . .	25,300·0	B_2	1,127,400,000	50,478·0	B_2	130,161,000,000
		B_2B_1	2,720,800,000		B_2B_1	43,022,600,000
		A_2	100,000,000		A_2	100,000,000
		A_2B_2	23,600,000,000		A_2B_2	40,807,700,000
British Columbia	438·0	B_2	115,000,000	1,645·0	B_2	2,300,000,000
		D_2	60,000,000		D_2D_2	5,136,000,000
					C	1,800,000,000
Yukon . . .	—			2,700·0	A_2B_2	250,000,000
					D_2D_2	4,690,000,000
North-West Territories .	—	—	—	960·0	D_2	4,800,000,000
Northern Islands .	—	—	—	6,000·0	B_2B_2	6,000,000,000
Total . .	26,219·31	—	414,804,193,000 †	74,062·84 ‡	—	801,966,117,000

* See page 3.

† In this total 20,000,000 has been deducted for the amount of coal of all classes already extracted in Alberta.

‡ This total does not agree with the figure given by Dowling.

Group II

Including seams of 2 ft. and over, at depths between 4,000 and 6,000 ft.

District.	Probable Reserves (Approximate estimate).		
	Area Square miles	Class of coal	Metric Tons.
Nova Scotia (marine areas, 3 to 5 mile limit) .	73	B_2	2,639,000,000
Alberta	204	B_2	12,700,000,000
British Columbia	11	B_2	2,160,000,000
Totals	287	—	17,499,000,000

Totals by Provinces

Groups I and II

	Metric tons.
Nova Scotia	9,718,968,000
New Brunswick	151,000,000
Ontario	25,000,000
Manitoba	160,000,000
Saskatchewan	59,812,000,000
Alberta	1,072,627,000,000
British Columbia	76,034,942,000
Yukon	4,940,000,000
North-west Territories	4,800,000,000
Northern Islands	6,000,000,000
	1,234,269,310,000

Production, Exports, Imports, and Consumption of Coal [109]

Nova Scotia, owing to its favourable geographical position, has been the largest producer till 1918, when Alberta slightly exceeded it, and has shown little variation in output since 1910. During the last three years the output from British Columbia has remained stationary, while from the other provinces, except Yukon, it has increased. Recent outputs are as under[1]:

Table IV

Production[1]

Province.	1915. Production, Tons (2,000 lb.).	1915. Value, Dollars.	1916. Production, Tons (2,000 lb.).	1916. Value, Dollars.	1917. Production, Tons (2,000 lb.).	1917. Value, Dollars.
Nova Scotia	7,161,170	16,050,308	6,912,140	18,814,662	6,327,091	19,410,737
New Brunswick	127,491	309,012	143,540	386,016	189,095	708,010
Saskatchewan	240,107	405,240	281,100	411,836	355,445	662,431
Alberta	3,360,818	8,283,079	4,559,054	11,386,577	4,736,368	14,153,685
British Columbia	2,005,013	6,455,011	2,884,061	8,075,190	2,433,888	8,235,710
Yukon Territory	0,724	38,896	3,300	13,200	4,872	29,232
Totals	13,207,023	42,111,182	14,883,395	38,817,481	14,046,759	43,199,831

Table V

The 1917 production comprised:

	Tons (2,000 lb.).
Anthracite (from Bankhead, Alberta)	108,225
Bituminous coal	11,154,251
Lignite	2,784,283
	14,046,759

[1] In 1918, the total production amounted to 14,977,926 short tons, of value $55,192,896 (*Ann. Rept. Min. Prod. Can.*, 1918).

Table VI

Exports, Imports and Consumption

	1916		1917	
	Tons (2,000 lb.)	Value, Dollars.	Tons (2,000 lb.)	Value, Dollars.
Production	14,483,305	38,817,481	11,040,759	43,199,831
Imports	17,580,693	38,280,000	20,857,409	70,562,357
	32,063,998	77,107,147	31,901,219	113,766,188
Exports	2,135,359	7,000,038	1,433,150	7,387,192
Re-exports	62,784	—	47,328	—
Consumption	29,865,850	70,107,760	30,123,735	110,818,811

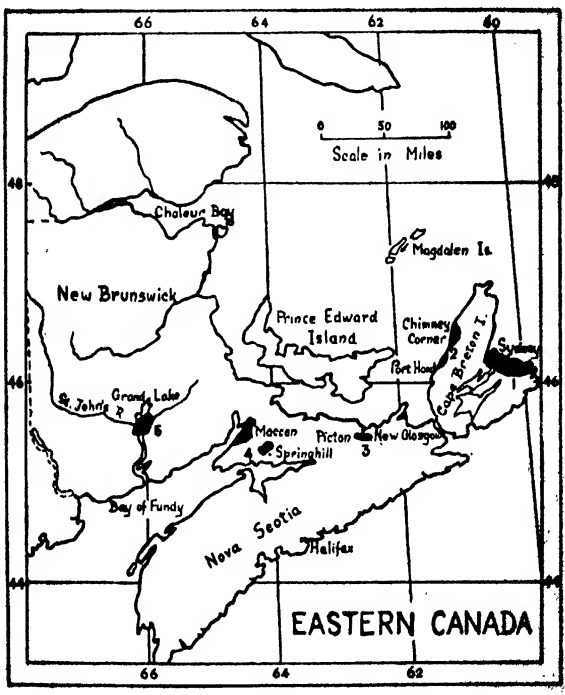
Nova Scotia

The Carboniferous rocks of Eastern Canada are in part the northward continuation of the Appalachian Mountains, and stretch from Fredericton in New Brunswick in broken outline through the north of the mainland of Nova Scotia into Cape Breton Island, where they dip under the sea and reappear across Cabot Strait in Newfoundland [113 p. 1] [121]. As already mentioned, the coal deposits of New Brunswick and Nova Scotia are of Carboniferous age.

The workable coals of Nova Scotia are found above the Carboniferous limestone in the subdivision termed the "Productive Coal-Measures." All the coal is bituminous in quality, and the analysis varies within comparatively narrow limits.

The reserves of Nova Scotia are small compared with those of Alberta, Saskatchewan and British Columbia, but the excellent quality of the coal, shipping facilities, and nearness to populous centres have enabled the mining companies to maintain a steady output. An import tariff of 53 cents per ton (2,000 lb.) on bituminous round coal and 14 cents on slack coal protects Nova Scotian coal against undue competition in the Montreal market from the cheaply-mined and water-borne United States coal. Anthracite is admitted duty free. But in general, the return on capital invested in the collieries of Nova Scotia has been small.

There are five distinct coal-fields, known as the Sydney, Inverness and Richmond on Cape Breton Island, Pictou and Cumberland on the mainland of Nova Scotia. Mining in the Richmond field has, on account of the uncertain occurrence of the seams and the inferior quality of the coal, been abandoned.



Cape Breton Island contains the most important coal-fields of Eastern Canada.

Sydney Coal-field [No. 1 on Map].—This field, the most important of eastern Canada, is situated with the deep-water harbour of Sydney as its central point, in the north-east corner of Cape Breton county, and extends slightly into Victoria

county. It consists of a series of parallel basins resulting from folding, of which the axes dip seawards at angles of from 5° to 12°. The land area is from 200 to 250 sq. miles in extent, with a length of 32 miles from N.W. to S.E. and a maximum width of 7 miles, and, as suggested by Richard Brown, is probably a segment on the southern edge of an immense submarine basin extending towards Newfoundland.

The structure and quality of the seams are subject to considerable change even in one basin. This, with the occasional thickening and thinning of the intervening strata, renders correlation of seams from basin to basin uncertain. There are from 6 to 9 workable seams from 3 to 9 ft. thick, and of an aggregate thickness of 40 to 50 ft. With the exhaustion of the thicker seams on the land area, thinner seams are being attacked and submarine mining is becoming general. Working has been extended under the sea to distances of 3 miles from the shore, and will probably be limited in this direction only by economic considerations.

Inverness Coal field (No. 2 on Map). Inverness Coal-field, fringing the western coast of Cape Breton Island, includes four distinct basins known as Port Hood, Mabou Inverness and Chimney Corner. The seams, as exposed on the landward area, dip westward, frequently at high angles, and the colliery workings are largely beneath the waters of the Gulf of St. Lawrence.

At Port Hood, one seam, 6 to 8 ft. thick, is being worked, and another, 360 ft. higher and 6 ft. thick, is said to occur. The seam dips at 21° beneath the sea, and flattens to 12° at the bottom of the dip incline, which is 2,000 ft. from the outcrop.

In the Mabou basin six seams, from 3 to 15 ft. thick, occur, and possibly aggregate 40 ft. of coal. The two upper seams, 7 and 8 ft. thick, were worked, but operations are stated to have ceased in 1908 [117/p. 42].

At Inverness, Charles Robb's section, given by the Geological Survey, 1873–4, shows seams of 3 ft., 5 ft. (reported), 7 ft., 4½ ft., 3 ft., and 3 ft. 9 inches. H. Y. Hind in 1873 also reported a somewhat similar section. The dip is from 15° to 20°, with steeper grades in places. In 1909 Mabou Mine, and in 1911 Port Hood Mine, were flooded by inbursts of water from the

sea. The 7-ft. seam is being worked, and produces annually about 250,000 tons, which is sent by rail to Port Hastings, 56 miles distant, and there shipped.

At Chimney Corner the seams measure 3 ft., 5 ft., and 3 ft. 6 in. They occur in a synclinal trough, and their workable extension seaward probably does not exceed 1 mile.

Pictou Coal-field [No. 3 on Map].—The Pictou field is situated in the centre of Pictou county, south of the town of New Glasgow. Its known workable extent is comprised within an area 11 miles long by 2½ miles wide. Coal is said to have been first discovered near Stellarton in 1798, and since then has been progressively mined. The structure of the field is very complicated, and still only partially understood. For descriptive purposes the field is usually divided into the three main divisions of Westfield, Albion, and Vale.

Albion, or Stellarton, the central and most important division, is separated from Westville on the west by the McCulloch fault, variously estimated at from 1,600 to 2,600 ft., but regarding which remarkably little is definitely known, and from the Vale division on the east by a disturbed and apparently barren area. It is remarkable for the thickness of some of its seams. In a section quoted by F. W. Gray [113/p. 26] 16 seams are shown, ranging in thickness from 2 ft. 8 in. to 34 ft. 7 in., and aggregating 188 ft. in 2,781 ft. of strata. Five of the seams exceed 20 ft. in thickness. But the thickness of the individual seams and the intervening strata vary greatly and rapidly, a feature rendering a correlation of the seams with those in the divisions to the east and west most uncertain. The dip of the strata is from 15° to 30° to the north.

In the Westville division there are four known seams, which, in descending order, are 17 ft., 12 ft., 6 ft., and 8 ft. thick. The average dip is 16° to the north-east.

The measures in the Vale division occur as a syncline, with a north-easterly axis and a cross width of 3 miles. It contains six seams of 3 ft., 3 ft., 3 ft. 9 in., 6 ft., 8 ft., and 2 ft., but here also the thickness varies considerably. The dip is from horizontal to 25°. This series is believed to be on a horizon above the Albion series, and to be separated from the latter by 1,600 ft. of strata.

Two companies only operate in the Pictou field, namely, the Acadia Coal Co. in the Albion division, and the International Coal Mining Co. in Westville, the respective outputs being about 400,000 and 150,000 tons per annum. Production in both areas has been seriously affected by underground fires. For economic reasons the former company closed down their collieries in the Westville and Vale divisions.

Cumberland Coal-field [No. 4 on Map]. This field is situated in the west of Nova Scotia on the western branch of the Bay of Fundy. In addition to the exposed Coal-Measures from which coal has for long been won, concealed Coal-Measures are supposed to exist beneath younger formations, and a borehole at Halfway River lake, in which a seam of 9 ft. was passed through at a depth of 2,350 ft., supports this idea. Faults are numerous, and one, the Athol fault, separates the two producing areas, Joggins to the north and Springhill to the south-east.

The Coal-Measures of the Joggins area outcrop in a fairly regular east and west line, 22 miles long, and dip from 19° to 50° to the south. They are supposed to be the northern limb of a synclinal basin, of which the contorted Springhill measures form the south-eastern edge. The latter measures are exposed for a length of about 7 miles, and dip at 25° to 30°, even up to 75° to the north-west.

The seams of the Joggins belt in general are thin, or split up by bands of shale, as at Maccan, and range from 2 to 7 ft. in thickness; those of Springhill have considerable thickness, one being 13 ft. and two each 11 ft. thick. Springhill seams are, like those of Pictou, subject to goaf fires, and give off firedamp freely.

It may be noted that the figures given in the table on the next page by no means represent the best analysis of Nova Scotia coals. They may be taken as a very moderately stated average, and as conservative figures [113/p. 38].

A matter claiming serious attention, and one coming more and more to the front in coal-mining everywhere, is hydraulic sand-filling or "flushing" of the goaf. The adoption of this system seems peculiarly desirable in certain parts of this province on account of the exceptional thickness of some of the seams, the extent to which mining beneath the sea is necessary,

Table of Average Analyses of Coal Samples taken from Collieries operating in the several Coal-fields of the Maritime Provinces

	Sydney, Cape Breton.	Inverness Co., Cape Breton.	Pictou Co.,	Springhill, Cumberland Co.	Joggins, Cumberland Co.	Grand Lake, N. Brunswick
Number of seam samples included in average	9	2	6	3	3	1
Moisture in coal :	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Total Moisture . .	3·7	7·0	2·4	2·6	2·9	1·13
Moisture left after drying . . .	2·6	5·3	1·7	2·1	2·2	0·09
Proximate analysis of dry coal :						
Fixed carbon . .	56·3	49·0	57·5	59·0	46·4	53·4
Volatile matter . .	30·4	38·5	29·6	33·0	37·8	32·2
Ash	7·3	12·5	12·9	8·0	15·8	14·4
Ultimate analysis of dry coal :						
Carbon . . .	75·8	65·4	73·0	76·6	64·8	70·3
Hydrogen . . .	5·1	4·5	4·5	4·9	4·4	4·6
Sulphur . . .	2·9	6·9	1·2	1·5	6·2	5·8
Nitrogen . . .	1·4	0·9	1·9	1·6	1·2	0·6
Oxygen . . .	7·5	9·8	6·5	7·4	7·6	4·3
Calorific value in British Thermal units :	13,060	11,960	12,970	13,520	11,869	12,89

and the liability in certain seams to underground fires. Safety to life and property and marked economy of the coal reserves would certainly be promoted.

New Brunswick

In the Province of New Brunswick large areas are occupied by rocks of Carboniferous age, but these consist chiefly of the lowest and barren strata, while a comparatively small area only is covered by the coal-bearing Millstone Grit. The "Productive Coal-Measures," which in Nova Scotia overlie the Millstone Grit, are here entirely absent.

Patches of thin coal are found in many places, but the only valuable occurrence is in the Grand Lake district of Queen's County [No. 5 on Map]. The extent of this area is 112 sq. miles, the measures are nearly horizontal, and the coal occurs at shallow depths. The deepest shafts do not exceed 50 ft.

and the coal at times is won by stripping the overburden. There are two seams of 20 inches and 10 inches, of which the upper only is worked except where, as at Minto, the two come together and form a 30-in. seam.

Analysis of Coal

Grand Lake Field

—	Moisture Per cent	Volatile matter Per cent	Fixed carbon Per cent	Ash Per cent	Sulphur. Per cent.	Calories.
King's Mine, Minto	0·9	32·2	53·4	14·4	5·8	7,160
" " (washed) . " .	—	34·0	56·6	9·4	4·9	7,680

The output has increased from 55,000 tons in 1910 to 268,212 tons (2,000 lbs.) in 1918.

The coal resources of the Grand Lake field are estimated by the Geological Survey at 138,000,000 tons, which, with 13,000,000 tons in the Beersville and Dunsinane areas, give a total of 150 million tons for the province.

Ontario

In the northern part of this province, on the Moose River, south of James Bay, beds of low-grade lignite occur in clays and sands of the glacial age. This lignite could be easily won, but from its remote position is not at present of economic importance [106].

The coals of the western half of Canada belong chiefly to the Cretaceous and its upward continuation, the transition beds of the Laramie formation. Tertiary and Jurassic coals occur to a limited extent.

Cretaceous strata, with undenuded remnants of Tertiary beds, first appear to the west of Winnipeg and extend to the Rocky Mountains, but coal deposits are few and comparatively unimportant till Alberta is reached.

The coals of this territory change through various grades from lignite in the east to anthracite in the west. East of

the 113th meridian, lignites, when thoroughly air-dried, have about 12 per cent. of moisture, whilst west of that line many, if not most, of the coals are less hydrous, and merge, in some instances, into bituminous coal indistinguishable from coal of Carboniferous age. But hydrous lignites and fuel of all intermediate stages also occur west of the line indicated (W. Dawson). In the mountain region the coal is mostly bituminous, and in the disturbed belt of the eastern foothills the fuels with 1·6 to 6·0 per cent. of moisture may rank as true coals. In the Cascade basin, in the mountains, where pressure from the west has overtilted the strata, anthracite of good quality has resulted.

Manitoba

Lignite is found in the south of this province on Turtle Mountain [No. 6 on Map], the southern half of which is in North Dakota and the northern half, of 48 sq. miles, lies in Manitoba. The formation is probably lower Tertiary, and contains thin seams of lignite which, Dowling states, appear to be "deposits which are limited in extent, though repeated over large areas." The lignite, though rather high in moisture and disintegrating on drying, is useful for local purposes. The production is very limited.

Saskatchewan

In this province two coal-bearing formations occur, namely:

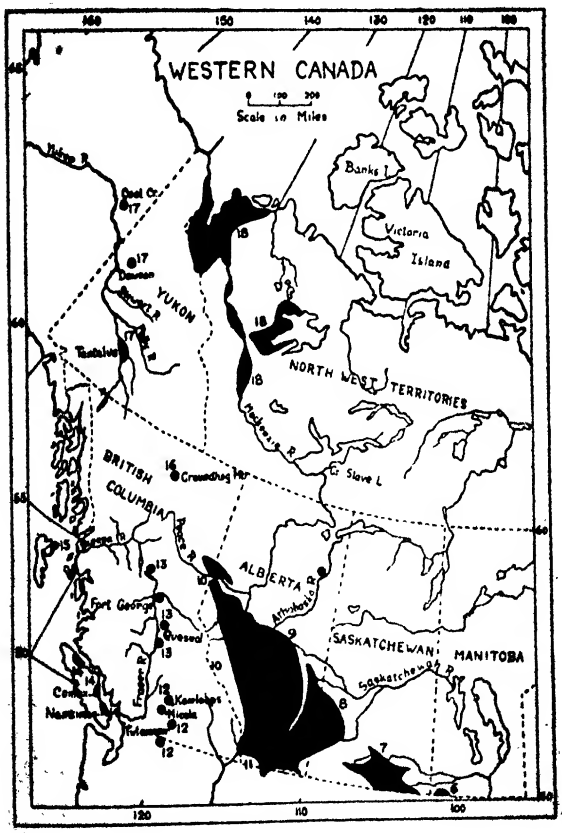
(1) Tertiary, in the extreme south of the Souris river, in the Estevan district, Wood Mountain and Missouri coteau.

(2) Cretaceous (Middle), in the Belly river division, extending eastward from the Saskatchewan-Alberta boundary to the vicinity of Swift Current.

Of these the Tertiary is the more important.

Souris Coal-field (Lower Tertiary) [No. 7 on Map].—The bulk of the coal-mining of Saskatchewan has been developed around Estevan, where seams of Tertiary lignite outcrop in the natural sections of the Souris valley. Outside of this mining area the Coal-Measures are mostly hidden beneath a heavy covering of boulder-clay, and little is known of their possibilities. The

area covered by these measures is estimated at 4,000 sq. miles. Dowling [117/p. 66] divides the coal formation of Estevan



into the upper, the middle, and the lower horizons, in the last of which an 8-ft. seam produces most of the coal won. Towards

the west this seam splits up into several small seams, but to the north-east it is reported to thicken to 15 ft.

North of the Estevan field, and in the hills to the west of the Souris river, coal is reported at various places in seams from 1 ft. to 18 ft. thick.

Lignites of Souris River Coal-field

	Moisture.	Volatile matter.‡	Fixed carbon.‡	Ash.‡	Sulphur.	Calories.
Western Dominions Collieries, Taylorton . .	18·0 *	49·0	42·9	8·1	0·6	5,940
Eureka Coal and Brick Co., Estevan . .	18·2 †	40·0	43·2	16·8	0·5	5,360

* Before air-drying, 28·6. ‡ Calculated on water-free basis.
† Before air-drying, 30·9.

Several mines operate in this district, and produce 95½ per cent. of the total in Saskatchewan, which, in 1918, amounted to 346,847 short tons.

Belly River Coal-field (Middle Cretaceous) [No. 8 on Map].—The Coal-Measures of this field, which lies in the west of the province, extend westward into Alberta. Coal-seams are few in this horizon, and are of importance chiefly on account of their wide distribution. A seam at the top of the formation, which is generally persistent in Alberta, occurs here only in isolated patches, and is 4 ft. thick on the Saskatchewan river, while further north it is found up to 8 ft. thick.

Eastward, the formation, according to Dowling, probably thins out beneath the overlying marine beds; southward it is overlain by upper Cretaceous shales, as proved at Maple Creek, where a borehole located the 4-ft. seam at a depth of 196 ft. and a 7-ft. seam 100 ft. lower. North of the Saskatchewan river the seams are sporadic; to the south they are more uniform, and probably more extensive.

The following table gives analyses of different lignites of the Belly River formation:

Locality.	Moisture.	Volatile.	Fixed Carbon.	Ash.
Kerrobert . .	21·32	34·00	39·93	4·75
Unity . . .	16·29	32·19	38·64	12·88
Brock . . .	25·70	26·95	28·42	18·93

Alberta

Dowling has estimated that the "actual" and "probable" reserves of coal in Alberta aggregate 1,059,927 million tons, or 87 per cent. of the total reserves in Canada.

The coal is Cretaceous, and occurs in three distinct horizons, which, in descending order, are known as:

(1) Edmonton and part of Paskapoo formation, at top of Cretaceous Lignite.

(2) Belly River formation, in middle of Cretaceous. Lignite.

(3) Kootenay formation, at base of Cretaceous.

The Paskapoo Series overlie the Edmonton Series over a great part of Alberta, and, in their lower beds, contain in certain areas small seams of coal, which supply local requirements, but are of little importance in comparison with the Edmonton seams.

Edmonton Formation [No. 9 on Map]. The Paskapoo and *upper* Edmonton Series occupy an area of 24,779 sq. miles, of which 22,475 sq. miles are estimated to be coal-bearing. Outside of this area an additional 29,930 sq. miles are underlain by a group of thinner seams in the Edmonton Series, occurring about from 500 to 600 ft. below the thick seam of the *upper* Edmonton beds. The total area, therefore, underlain by available coal of this formation is 52,405 sq. miles [*cf.* p. 476]. The estimated "actual" coal reserves are 383,697 million tons (metric), and "probable" coal reserves 417,261 million tons (metric), aggregating 800,958 million tons, of which 789,600 million tons are lignitic or sub-bituminous and 11,358 million tons are low-carbon bituminous (Class B).

The Edmonton formation occurs as a synclinal basin, extending in Canada from latitude 49° N. to about 55° 30′ N. The axis of the syncline is east of and parallel with the Rocky Mountains, from which the western limb dips rather steeply to the east, while the eastern limb dips gently to the west. Toward the north the measures flatten, the trough widens, and the coal-seams thicken. Tertiary sandstones overlie the central portion trough.

The seams are found in an upper horizon at the top of the

formation, and in a lower horizon at from 500 to 600 ft. below the upper. In the upper horizon a group of seams come together in places to form the "Big Seam." South of Bow the total thickness of coal is 5 ft., but it thickens to the north-west, and at Calgary is 13 ft. in a single seam at a depth of 1,800 ft. beneath Tertiary strata. West of Edmonton it is 25 ft. thick, and at the Grand Trunk Pacific crossing of the Pembina river it splits into at least two 10-ft. seams. The coals of the lower horizon are mined at Edmonton, Tofield and other places.

The change in the upper horizon from lignite in the extreme north-eastern area to coking coal in the foothills is shown in the following analyses quoted by Dowling:

	Moist.	Vol.	F.C.	Ash.
Head of Pembina River (west of axis) .	4·32	33·43	56·47	5·14
Saskatchewan River (east of axis) .	11·88	35·31	47·06	5·08

Coal from Strathcona Mine, Edmonton (air-dried)

Moist.	Vol.	F.C.	Ash.	Calories.	Fuel ratio.	C.H. ratio.
18·2	33·6	38·9	9·3	4,877	1·15	9·0

Loss on air-drying, 5·8 per cent. [110].

Belly River Formation [No. 8 on Map].—This formation extends westward from Saskatchewan into eastern Alberta, in which 16,000 sq. miles are underlain by it. It stretches in Canada from the international boundary to latitude 53° N., a length of about 250 miles. Sufficient data are not available from which to estimate even approximately the amount of coal contained in this area, but the available coal must be enormous. In the northern part of the area the seams appear to be thin. Near Medicine Hat two 5-ft. seams outcrop in the river banks; going westward, the coal improves in quality at Taber, and still more at Lethbridge. The hydrous character of the coal diminishes as the mountains are approached, as indicated in the following analysis [2/p. 479]:

Locality.	Thickness. ft. in	Moisture.	Vol.	F.C.	Ash.
Redcliff, near Medicine Hat .	5 0	20·54	33·26	41·15	5·05
Ten miles west of Medicine Hat	4 0	16·82	31·90	43·98	7·30
McPhee mine . . .	2 7	11·35	29·98	51·63	7·04
Taber mine . . .	3 3	7·21	39·18	46·36	7·22
Galt Collieries, Lethbridge .	5 6	4·73	34·61	50·43	9·83

But samples fresh from Taber mine and Galt Collieries gave the following results [118/p. 84]:

	Moisture.		Calculated as Water-free			
	Mine.	Air dried	Volatile.	F C	Ash.	Calories.
Taber Mine .	13·0	11·7	39·0	49·9	14·1	6,130
Galt Collieries .	8·4	7·9	37·5	51·5	11·0	6,510

The Belly River coals have been proved beneath the Edmonton formation at:

Tofield .	depth	1,050 ft.	coal 4 ft.
Edmonton .	"	1,400 "	" 6 "
Calgary .	"	2,502 "	" 5 "
Calgary .	"	2,676 "	" 7 "
Calgary .	"	2,875 "	" 4 "

Kootenay Formation [No. 10 on Map]. This formation is hidden beneath the younger members of the Cretaceous system in the undisturbed areas east of the Rocky Mountains, and is only exposed in the denuded domes of the anticlines in the foothills and in the upheaved strata of these mountains where intense erosion has removed the overlying measures. The formation in the mountain region occurs in long strips of uplifted fault blocks, dipping in general to the west in monoclinal fashion, but synclinal troughs are also found. It occurs both in the outer ranges and in the foothills from near the international boundary to the Athabaska river, beyond which most of the coal-bearing areas are in the foothills. The formation, 3,000 ft. thick at Elk River valley, thins to the north, and is probably only 200 ft. thick east of the main range of the Rockies [2/p. 482].

It is estimated that, of the "actual" and "probable" reserves, 1·7 per cent. is semi-anthracite and 98·3 per cent. is coking and non-coking bituminous and usually of high grade [122/p. 11]. The anthracitic character varies with the degree of dynamic action to which the beds have been subjected.

Kootenay coal is the best found in the Prairie Provinces, and examples of its occurrence are:

Coleman area.—Three of the principal seams are 16, 10 and 18 ft. thick.

Blairmore area.—This area contains seams 10, 17, 3½, 3½, 17 and 6 ft. thick.

Livingstone basin.—In the north, 13 seams, with 43 ft. of coal, and in the south, 21 seams, with 125 ft. of coal, are believed to occur. This area is not yet actively mined.

Moose Mountain area, lying west and south of Calgary, has seams 7, 8 and 20 ft. thick.

Cascade.—This field is nearly 90 miles long. Between the Bow and Kananaskis rivers 15 seams aggregate 85 ft. in thickness. At Bankhead the coal approaches anthracite.

Bighorn basin.—This field has a length of 46 miles, in which at various places from 3 to 14 seams, aggregating, respectively, from 22 to 88 ft., occur. Seams of 21, 7½ and 4½ ft. are being mined at Mountain Park. The coal is coking. Coal is also found in the Kootenay formation in various other localities in the Rockies and in the foothills.

Average Analysis

Coal Field	Moisture.	Vol. matter	Fixed C	Ash.	Calories.
Blairmore	0·50	28·30	58·50	12·70	7,000
Bighorn .	1·13	24·40	67·90	6·57	7,537
Cascade .	0·40	14·60	71·50	13·50	7,266

British Columbia

The coal-fields of British Columbia may be grouped into:

Rocky Mountains field in the east of the province.

Southern and Central fields.

Vancouver and Queen Charlotte Islands fields in the west.

The coals of importance are Cretaceous. They occur only in disjointed areas, and their correlation depends, therefore, largely on fossil evidence, while their exact geological age is, in certain cases, uncertain.

Rocky Mountains Field.—This field, lying on the Elk River and the western side of the Rockies, comprises the important Crow's Nest Pass basin and, immediately to the north, the upper Elk River basin, which passes, at its northern end, into Alberta at Kananaskis Pass. Crow's Nest basin [No. 11 on Map] has an

area of 230 sq. miles, and is the most important field being mined in British Columbia. The Coal-Measures belong to the Kootenay Series, and contain 22 seams and 200 ft. of coal of which 100 ft. are considered workable. In the smaller area of the upper Elk River the same measures occur, but the number of seams varies. Sections showing 80, 68, 182 and 97 ft. of coal are reported, and one seam on Lewis Creek is 31 ft. thick. The coal is of quality similar to that of Crow's Nest.

Analysis of Crow's Nest Coal [120]

Coal air-dried.	Moist	Vol	F C	Ash	Calories	Fuel ratio	C H ratio.	Coke.
Corbin, No 4 mine	0·5	24·0	61·1	14·8		2·50	17·9	poor
Michel Colliery	0·7	22·4	65·0	11·9	7,306	2·90	16·9	—
Coal Creek Colliery	1·3	26·0	63·8	8·9	7,578	2·45	17·3	—

Small occurrences of Tertiary coal also are reported from Bull River, Kettle River, Midway and Okanagan.

Southern Field.—At Princetown [No. 12 on Map], seams of Tertiary lignite, 4½, 6½ and 18½ ft. thick, occur within 50 ft. of the surface. Boring in the vicinity indicates great variation or want of continuity in the beds. Woody fibre is still apparent in some of the seams. The analysis of the thick seams is: Moisture, 16; Vol. matter, 37·5 Fixed Carbon, 42. Ash, 4·5 per cent. At Tulameen, Tertiary bituminous coal is found in seams ranging from 5 to 12 ft. thick.

Nicola valley [No. 12 on Map] coal is of similar age, but ranks higher as sub-bituminous. The analysis is: Moisture, 4; Vol. matter, 37·5, Fixed Carbon, 44·5, Ash, 14, Calories, 6,240 [120]. The thickest seams occur at Coldwater Creek, and seams, 6, 10, 5 and 12 ft. thick, are being worked south of the Nicola River, while north of the river two seams of 4 ft. and 5 ft. have been located.

Central Field.—Lignite of low grade is found at Alexandria, Quesnel and Fort George [No. 13 on Map]. In the extensive region between the Fraser River and the Coast Range, concealed coal-fields may exist beneath the Tertiary volcanic rocks. Lignite, under disturbed and rather unpromising conditions, is found on the Nazco, Blackwater and Nechako Rivers and on

Fraser Lake. On the Coast range, on a branch of the Dean or Salmon River, excellent lignite in a seam 4 ft. thick occurs.

In the valley of the Bear River 3 seams of bituminous coking coal, aggregating 21 ft., occur, and probably contain 150 million tons.

On the southern tributaries of the Skeena River, lower Cretaceous Coal-Measures, known as the Skeena Series, occur, as described in 1907 by W. W. Leach for the Geological Survey, in long narrow basins left in troughs of the folded underlying volcanic rocks, erosion having removed the more elevated portions on the ridges. In Morice River district coal has been found at *Clark's Fork*, where 3 seams, totalling 7 ft., and a seam of 10 ft. have been proved; on *Goldstream*, where bituminous coal is exposed in 3 seams of 8, 6½ and 3½ ft.; and on *Coal Creek*, where hard coal occurs in 4 seams from 4 to 7 ft. thick.

On another tributary, the Telkwa River, coals varying from bituminous to semi-anthracite give the following analyses [117/p. 104].

Seam	Moisture	Vol.	F.C.	Ash.
Cassiar Coal Co., 7 ft. . . .	1·92	30·45	61·30	6·35
Telkwa M.M. and D. Co., 5¼ ft. .	1·36	10·87	80·82	6·95

Vancouver Fields [No. 14 on Map]. The coals of Vancouver Island are, so far as determined, Upper Cretaceous, and occur in a series of rocks known as the Nanaimo Series. This series, originally nearly 10,000 ft. thick, was, in post-Eocene times, elevated, folded and dislocated, and subsequently greatly denuded. The chief coal-bearing areas lie in low rolling and hilly country between the east coast and the mountains of the interior. They consist of the Nanaimo field, with a productive area of 65 sq. miles, and, to the N.W., the Comox field. The Suquash, a smaller field in the northern end of the island, was till recently quite undeveloped. Other basins probably containing workable coal are Quatsino Sound, near Suquash, Alberni in the centre of the island, and Cowichan south of Nanaimo.

In *Nanaimo* field, the measures are described as moderately disturbed with a low dip to the north-east. The coal occurs chiefly in three seams in the lower part of the measures. The seams, though persistent, vary greatly in thickness. At times

a seam of clean coal, 30 ft. thick, diminishes within a distance of 100 ft. to 2 or 3 ft. of dirty coal. The coal cokes readily. A typical analysis is:

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur	Calories in dry coal.
1·6	39·7	47·7	10·1	0·9	7,130

The *Comox* field contains several seams of which three have been mined, the lowest, 7 ft. thick at the Union mine, being the thickest. Mining centres round Cumberland, where the seams attain their greatest importance. Comox coal has volatile matter 30 per cent., fixed carbon 57 per cent., and calories 7,220.

At *Suquash*, several seams occur, and two are workable. Unlike those of Nanaimo and Comox, they are regular in thickness, but are thin and mixed with persistent "bone" partings. One seam, 5 ft. thick, has been mined. The available analysis indicates a water content of 5·2 per cent. in air-dried coal, and considerably more ash than in the more southern coals.

Queen Charlotte Islands (No. 15 on Map). Coal both of Cretaceous and of Tertiary ages is found on these islands. The former ranges from semi-anthracite to low-carbon bituminous. The Tertiary coals are lignitic, mostly brown with a woody structure, but sometimes passing into a black more coal-like fuel.

The Cretaceous coal occurs chiefly in a syncline in the south of Graham Island, between the Skidegate channel and Yakoun Lake. Outcrops of coal apparently from 6 to 12 ft. thick, are found at Camp Wilson, Camp Robertson and Camp Anthracite.

The following are analyses of Graham Island Cretaceous Coals:

	Moisture.	Vol. matter	Fixed C	Ash.
Camp Wilson .	2·44	35·96	48·64	12·96
Camp Robertson .	1·20	29·13	47·52	22·15
Camp Anthracite .	1·52	8·69	80·07	9·72

Near Cowgitz some of the semi-anthracite contains nearly 7 per cent of moisture, and is badly crushed. The mining of this coal was abandoned in 1871, but another attempt was made in 1912, with what result is not recorded

In the north-eastern part of the island, on the shore at Skonun Point, 10 seams of tough woody lignite, from 1 ft. to 15 ft. thick, are exposed.

Northern British Columbia.—The most important coals yet discovered in this region are the semi-anthracites and anthracites of the Groundhog Mountain area [No. 16 on Map] in latitude 57° N. It is estimated that 170 sq. miles are coal-bearing, and contain 8 seams aggregating 30 ft. in thickness.

Lignites occur on the Kispiox, Sustut, Peace and Liard Rivers; bituminous coal near Peace River cañon and on the Taku River [122/p. 14].

The actual and probable reserves in British Columbia are estimated to occur in the following proportions: semi-anthracite, 1·9 per cent.; bituminous, 85·4 per cent.; low-carbon bituminous, 3·3 per cent.; cannel, 2·4 per cent.; lignite, 7·0 per cent.

Yukon Territory

The coals of the Yukon are found in Tertiary and Jura-Cretaceous rocks. The most important coal areas, going from south to north are: Whitehorse area, Tantalus area on the Lewes River, and Rock Creek area. The first and second are Jura-Cretaceous, the third Tertiary.

Whitehorse area [107]. Three seams, 9 ft. 8 in., 10 ft. 4 in., and 2 ft. 6 in. thick, dipping 42° to the N.E., are exposed. The coal has 22 to 25 per cent. ash.

Tantalus area [108] [No. 17 on Map].—The coals range from high-grade lignite, to coking bituminous coal. They occur in an upper horizon near the top of the Tantalus conglomerate, and in a lower horizon in the upper portion of the Laberge rocks.

In the upper horizon, at the Tantalus mine, three seams 3 ft., 6 ft. 6 in., and 7 ft. 6 in., in descending order, are found, and assay:

Seam.	Moisture.	Vol. matter.	Fixed C.	Ash.	Coke.
3′ 0″	0·82	25·12	66·00	8·03	74·06
6′ 6″	0·76	24·74	58·60	15·90	74·50
7′ 6″	0·75	23·01	55·21	20·43	75·64

At Tantalus Butte, across the Lewes River, the general conditions of the measures are similar to the foregoing, but no coal has been exposed. Moisture content is about 13 per cent. and ash 2·6 to 5·9 per cent.

Rock Creek area [115].—Yukon Territory contains extensive areas of Tertiary lignite. The largest area, comprising 200 sq. miles, extends for 70 miles from Klondike valley W.N.W. to Cliff Creek. Several seams of lignite occur, and the most important property at present is that of the Sourdough Coal Co., on Coal Creek, a tributary of Yukon River. The seams range in thickness from 4 to 20 ft.

The following are analyses of coal from Sourdough Mine [2/p. 518]:

Moisture	Vol. matter	Fixed C	Ash
17·10	34·50	38·40	10·00
14·57	33·11	37·15	15·17

The coal is used at Dawson.

North-West Territories

According to D. B. Dowling [2/p. 521], extensive areas of "actual" and "probable" lignite-bearing measures occur on the western side of Great Bear Lake, in the valley of the Mackenzie River, and particularly in the delta region of this river [No. 18 on Map]. The Fort Norman Tertiary basin extends a short distance up Great Bear river, and is estimated to contain 4,800 million tons of lignite in three seams reported to be 3, 4 and 9 ft. thick.

In the region of the Mackenzie delta, Cretaceous rocks, over a wide area, contain a few exposures of coal. On Hortion river, S.W. of Franklin Bay, a 4-ft. seam and several smaller seams are found.

Northern Islands

In the Northern Islands, coal, and cannel-coal, probably from the base of the Carboniferous system, have been found. Tertiary coal has been exposed on Baffin Island, Bylot Island, and on Elsmere Island near Lady Franklin Sound. At Cape Murchison a 25-ft. seam has been reported. The probable reserves of coal are estimated at 6,000 million tons.

Development of Lignite in Canada

In Canada, as in many other countries, the conversion of raw lignite into a higher grade fuel is a question of much importance, and, under Government auspices, is being in-

vestigated in Canada on the lines of briquetting carbonized lignite for the production of an artificial lignite. Similarly, in New Zealand, the use of "brown coal" in gas-producers and for low-temperature distillation is engaging attention, and has been investigated to a certain extent with encouraging results [119].[1] The use of coal generally in improved ways is referred to succinctly by James White [122/p. 24].

Powdered coal as a fuel is coming slowly but steadily into use, and, in U.S.A., about 10 million tons of coal are consumed annually in this form. Its uses and application have been dealt with by C. F. Herington [114]. In Burma the use of powdered Tertiary coal, generally hydrous and of indifferent quality, is now being investigated jointly by the Railway Department and the Burma Corporation Ltd. The almost perfect freedom from smoke when powdered coal is burnt is very striking.

NEWFOUNDLAND

J. P. Howley, writing in 1913, states that the coal-areas of this island are still undeveloped, a fact due to the claim of the French to the exclusive right to the foreshore on the western coast under their fishing rights, while they held no power to work the mines. This *impasse* was recently ended.

Rocks of the Carboniferous series occupy 1,100 sq. miles to the south of St. George Bay, and about 500 sq. miles in the Humber River valley and its branches. The former is regarded as an extension beneath Cabot Strait of the same series in Nova Scotia.

The Carboniferous series in St. George Bay district has been much folded, and contains several small synclinal troughs of the "Productive Coal-Measures." On the upper reaches of the Great Codroy River, a seam of 9½ ft. thick and one 23 ft. thick with 15 ft. of coal are found in an almost vertical position. The coal is of good quality, but the seams dwindle in thickness within a short distance. On the Middle Barachois River 12 seams, ranging from a few inches to over 5 ft., are exposed, and on Robinson's River 3 seams are seen, one being 4 ft. 2 in. thick.

[1] In N.Z. the term "lignite" is confined to fossil fuel retaining more or less the woody structure of the original components, while in Victoria, Australia, this fuel is termed "brown coal."

In the Humber district on Aldery brook, 6 seams, ranging from 1½ to 6½ ft.; on Coal brook, 6 seams, ranging from 1 to 3½ ft.; on Kelvin brook, 3 seams, ranging from 2½ to 6 ft.; and on Goose brook, 9 seams, ranging from 1 to 3½ ft., have been proved.

The following analyses are of typical samples of Newfoundland coal [2/p. 437-8]

	Moisture	Vol.	F C	Ash.	Sulphur.
Bay St. George . .	4·78	29·28	54·47	10·43	3·04
Humber	5·02	31·25	54·03	8·66	1·04

It may be summarized that "there are several seams in the different sections large enough, and of sufficiently good quality, to be reckoned as workable coal-seams" (Howley).

TRINIDAD, JAMAICA, WINDWARD ISLANDS, BRITISH GUIANA
(see p. 158)

AUSTRALASIA

AUSTRALIA

New South Wales

Geology of the Coal-bearing Rocks

The work of investigators on this subject has been summarized by E. F. Pittman [131/p. 309; (1), Government Geologist of New South Wales, in the following record:

Geological Age	Maximum Thickness of Strata.	Locality.	Character of Coal.
I. KAINOZOIC, *Eocene to Pliocene*	About 100 ft	Kiandra, Gulgong, Chouta Bay, etc	Brown-coal or Lignite.
II. MESOZOIC, *Triassic or Trias-Jura*	About 2,500 ft	Clarence and Richmond R.	Coal suitable for local use only.
III. PALÆOZOIC, *Permo-Carboniferous*	About 13,000 ft *	Northern, Southern and Western Coalfields	Good gas, house and steam coal.
IV. PALÆOZOIC, *Carboniferous* .	About 10,000 ft	Stroud,† Bullah Delah	Very inferior coal, with bands; of no value.

* David states 15,000 to 16,000 ft [126 p. 311].

† Permo-Carboniferous rocks also occur north of Stroud towards Ward's River, and a 30-ft. seam of anthracite coal of possible value has been exposed close to the base of the measures [126 p. 279].

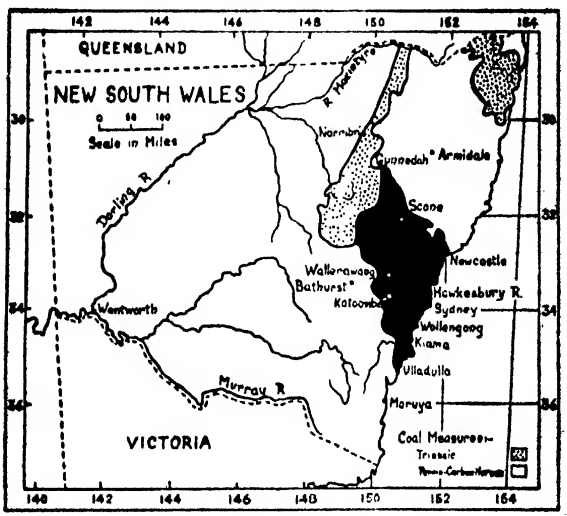
I. Kainozoic

Lignite or brown coal, of undetermined but limited extent, has been found in deep alluvial gold beds, overlaid by basalt.

One deposit, 30 ft. thick, occurs at Kiandra, but, as a rule, the beds are from a foot to 3 or 4 ft. thick, and are, at present, of no commercial value.[1]

II. Mesozoic

Pittman regards the Mesozoic Coal-Measures of the Clarence and Richmond district, south of the Queensland



border, as either Triassic or Trias-Jura.[2] They stretch for about 120 miles along the north-east coast of New South Wales,

[1] The writer, while visiting many years ago a "deep lead" gold-mine near Ballarat, was shown a similar brown-coal deposit, in which the bones of a *gigantic kangaroo*, with a chisel-shaped bone implement alongside, were said to have been found during underground operations. These remains are now in the Ballarat Museum. The implement is now discredited, and the evidence being considered inadequate, the matter is unsettled.

[2] Valuable seams of Mesozoic coal are being extensively worked across the border in Queensland, and B. Dunstan, Government Geologist, says that, after due consideration, the old term, "Trias-Jura" has been deleted, and the terms "Triassic" and "Jurassic" have been substituted as the names of the individual systems in that State [127/p. 1].

and extend northward into Queensland; their greatest width from east to west is 65 miles.

These measures have been divided as under:

Shales, possibly containing coal seams . .	Upper Clarence Series
Thick bedded sandstones (about 100 ft.) . .	Middle Clarence Series
Shales and sandstones (about 300 to 1,000 ft.) with coal seams	Lower Clarence Series
Thick beds of coarse conglomerate . . .	

From the lithological similarity of these measures to the Hawkesbury Sandstones they were formerly regarded as Triassic, a view which might receive some support from the fact that both the Clarence coal and the Ipswich coals, with one doubtful exception, lie beneath identical massive current-bedded sandstone. The Ipswich coals (excluding the Walloon series of the same district) are referred to the Trias by Dunstan [127/p. 3] and A. B. Walkom [133]. There is a frequent occurrence in the Clarence measures of *Taeniopteris Daintreei*, a fossil not found in the Hawkesbury Series.

According to J. E. Carne [124/p. 36], the only coals of the basin occur in the Lower Series. There are at least five seams of coal with interstratified shale beds varying in thickness from 2 to 37 ft., with rarely more than a foot of clean coal between the bands. The coal is high in fixed carbon, comparatively smokeless, and remarkably free from sulphur, but high in ash and unsuitable for other than local use, as recently confirmed in a report by Carne [125].

On the western side of the Main Divide the Middle Clarence Series is also found, dipping westerly under the central plains, and is regarded by Pittman as forming the southern extension of the intake beds of the great Australian artesian water basin. Many artesian water bores put down over this great area (569,000 sq. miles) [134] have passed through coal of undetermined thickness and quality, but in any case the presence of water under pressure in the strata renders the possibility of coal-mining most unlikely.

III. Palæozoic—Permo-Carboniferous

The Permo-Carboniferous coal-fields of New South Wales have been divided into the Northern, Southern and Western

groups, which, however, are merely geographical divisions of one large coal-basin.

While the area covered by this system extends over some 16,550 sq. miles, these coal-fields are practically comprised within a rhomboidal-shaped figure, of which the four angles are at Newcastle, Wollongong, Wallerawang and Scone, and of which the extent is about 8,000 sq. miles. Coal occurs beyond the limits of this area as, for example, to the south and west of Wollongong, where, however, it is of little present value, and far north at Gunnedah, where a limited quantity of good coal is found.

The Permo-Carboniferous system, with the overlying Triassic and underlying Carboniferous, may be tabulated as under:

		Thickness in feet.
TRIASSIC	*Hawkesbury Series*, divided into Wianamatta Shales, Hawkesbury Sandstone, Narrabeen Beds	
PERMO-CARBONIFEROUS	*Upper, or Newcastle, Illawara and Lithgow Freshwater Coal-Measures*, with an aggregate of 35 to 40 ft of workable coal	1,400 to 1,500
	Dempsey freshwater beds	2,200
	Middle, or Tomago, or East Maitland Coal Measures, with an aggregate of about 18 ft of workable coal	500 to 1,800
	Upper Marine Beds	5,000 to 6,400
	Lower, or Greta, and Clyde River Coal-Measures, probably entirely freshwater, with an aggregate of about 20 ft of workable coal	100 to 300
	Lower Marine Beds (Basal beds 200 ft thick, contain numerous ice-grooved pebbles)	4,800
CARBONIFEROUS	Total maximum thickness	17,000

General Review of the Coal-fields

Pittman [131] gives a general review of these coal-measures, of which the Northern, or Newcastle, coal-field has been described in exhaustive detail by T. W. E. David [126], the Southern, or Illawarra, by L. F. Harper [129], and the Western, or Lithgow, by J. E. Carne [124].

For descriptive purposes it may be taken that the centre of the basin occurs at or near Sydney, where the supposed topmost, or "Bulli," seam is being worked by the Sydney Harbour Colliery at a depth of 2,882 ft. The strata rise from this point

at a low angle to the northern, southern and western coal-fields, in each of which certain coal-seams are extensively worked. It has, however, to be noted that the quality and thickness of the individual seams are, as might be expected over such a wide area, subject to great variation, so much so that the valuable seams of one district are frequently of little or no value in the other districts. Further, it may be admitted that surface contour or other conditions did not admit of either an interrupted growth or deposition of coal-forming vegetation on a given horizon over the whole basin, and that from this cause one seam or another may be absent within certain areas. It would be imprudent, therefore, to insist in every case on a definite correlation of coal-seams over long distances where the available evidence is still scanty.

The Upper Coal-Measures of the Northern coal-field have their continuation in those of the Southern and the Western coal-fields, and in those tapped under Sydney Harbour. The "Wallarah," or No. 1, seam of the north may be correlated with the "Bulli," or No. 1, seam of the south, and with the Katoomba, or No. 1, seam of the west, all of which form the top of the Permo-Carboniferous system, and are immediately overlaid by the Triassic. It has been usually held that the prolongation of this No. 1 seam was to be found in the topmost seam beneath Sydney Harbour, but some doubt has been thrown on this correlation by L. F. Harper, who, from his recent investigations in the Southern coal-fields, considers it probable that the "Bulli" seam and the underlying "Four foot" seam gradually died out toward the Sydney area, and that the seam there worked is the third, or "Dirty," seam of the south [129/p. 205].

The Upper Coal-Measures

Northern Coal-field

Seams.	Thickness.	Character.
1. Wallarah	About 11 ft.	Splint, steam coal
2. Great Northern	About 20 ft.	Splint and bituminous coal
3. Fassifern	Up to 25 ft.	Contains many bands
4. Upper Pilot		Not workable
5. Lower Pilot		Not workable
6. Australian	From 7 to 29 ft., 7 ft. worked	Mostly bituminous
7. Burwood	From 6 to 8 ft.	Bituminous

Seams.	Thickness.	Character.
8. Nobbys		Not workable
9. Dirty	6 to 10 ft.; splits into two seams in places	
10. Yard	About 3 ft.	
11. Borehole . . .	From 4 to 22 ft., usually 8 to 9 ft.	Bituminous; of excellent quality
12. Upper and Lower Sandgate	From 4 to 6 ft.	Usually not workable

The Wallarah, Great Northern, Australasian, Burwood and Borehole seams only are being worked. The Borehole seam has, on account of its superiority as a household and gas coal, been by far the largest contributor to the output of this, the most important coal-field of New South Wales. It is, however, becoming rapidly exhausted in the Hunter River Delta area, and is yielding place as premier producer to the Greta seam of the Lower Coal-Measures.

Further reference to quality will be found under analyses. The other seams, so far as proved, are valueless under present conditions:

Southern Coal-field

Seams.	Thickness	Character.
1. Bulli . . .	2 to 11 ft., usually 6 to 7 ft	Semi-bituminous, excellent steam and coking coal
2. Four Foot . . .	About 4 ft	Semi-bituminous
3. Thick, or Dirty . .	About 17 ft.	Quality variable; possibly workable in the future in parts to the south
4. Oil Shale . . .		Kerosene shale; formerly worked on small scale at Mount Kembla Colliery
5. Unnamed . . .		
6. Unnamed . . .	Between Nos. 6 and 7, silicified wood horizon	Not workable
7. Unnamed . . .	6 ft., including numerous bands	

No. 1 seam has been extensively, and is increasingly worked from Mount Kembla, near Wollongong, northward to the Metropolitan Colliery, a distance of 22 miles, and No. 2 has been mined to a small extent. In the district south of Mount Kembla No. 1 seam thins, and eventually disappears; No. 2 continues further south, but deteriorates; No. 3 improves greatly within limited areas; and No. 4 seam improves in thickness and quality. The other seams are consistently inferior, and finally disappear in the same direction.

At the main shaft of the Metropolitan Colliery the Bulli seam is 12 ft. thick, but, at 3¼ and 11¼ miles to the north, boring proved it respectively 4 ft. 8½ in. and 4 ft. 2 in. thick, while correspondingly the Four Foot seam was 6 ft. 1 in. and 5 ft. 3 in.

The Southern coal is an excellent steam coal, largely used by the ocean-going steamers visiting Australia; coke made from it is exceedingly strong, and suitable for smelting purposes in blast furnaces.

Western Coal field

Seams.	Thickness	Character.
1. Katoomba . .	From 2 to 6 ft.	Quality indifferent
2. Dirty . . .	Up to 18 ft., including bands	No. 3 seam of Southern Coal-field
3. } Coal horizons		
4. } marked by thin		
5. } coaly streaks		
6. Upper Irondale . .	From 1 to 8 ft.	Rather high in ash; used locally
7. Lithgow . . .	About 11¼ ft (lower 6 ft worked)	Good steam and coking coal

Seams Nos. 1 and 6 have been worked only to a small extent; all the collieries in the Lithgow valley, and some in the Wallerawang and Cullen Bullen area in the western part of the district, work the No. 7, or "Lithgow," seam.

The coal is a good steam coal, somewhat inferior to the Southern coal, from which it differs in having a higher percentage of hygroscopic moisture, volatile hydrocarbon, and ash, and a lower percentage of fixed carbon. It produces a coke useful for metallurgical purposes.

Carne [124/p. 219] gives the following comparison of coal from the Southern and Western coal-fields

	Southern Coal-field	*Western Coal-field.*	
	Bulli Seam 10 Collieries	Lithgow Valley. 7 Collieries.	Wallerawang-Cullen Bullen. 9 Collieries.
Hygroscopic Moisture	0·97	1·83	2·62
Volatile Matter	23·10	31·40	29·76
Fixed Carbon	65 26	54 62	53·82
Ash	10·67	12·12	13·79
	100 00	99·97	99·99
Sulphur in coal	0·462	0·655	0·532

If Irondale colliery, which works No. 6 seam, be omitted, the Wallerawang is slightly less in ash than the Lithgow Valley group.

The Middle Coal-Measures

These measures outcrop at East Maitland on the Hunter river, W.N.W. of Newcastle. The coals are of both splint and bituminous order, more tender and friable than those of the Upper and Lower Coal-Measures, and suitable chiefly for steam, gas, smithy and domestic purposes, but not for export. The seams are subject to splitting by bands, which frequently increase to great thickness. The principal seams, of which the most important are the second, third and fifth, are as follow:

Summary of Tomago Coal Seams

	Thickness in ft.	Thickness worked.
1. Top Seam, or Donaldson's Seam .	4 to 6	3
2. Big Ben, or Tomago Thick Seam .	7 to 10	—
3. Tomago Thin Seam	2½ to 3	—
4. Scotch Derry Seam	—	Not workable
5. Rathluba Seam	5½ to 11	4 to 4½
6. Morpeth	4½ to 8	Not worked

The aggregate of coal is about 40 ft., of which a thickness of about 33 ft. is in seams upwards of 4 ft. thick, and the total thickness worked is about 18 ft.

A typical analysis of Tomago coal is [132]: Hygroscopic Moisture, 1·60; Vol. matter, 35·85; Fixed C., 53·85; Ash, 8·70; Sulphur, 1·222; Sp. gr., 1·336; Coke, 62·55; Evaporative power, 12·5.

These measures are not represented in the Western Coal-field, or in the southern part of the Southern Coal-field, where in both cases the Upper Coal-Measures rest on the Upper Marine beds; but a borehole put down in 1891 at Bulli Colliery on the flat between the colliery and the sea intersected, at a depth of 717 ft. below the lowest coal seam of the Upper Coal-Measures, a seam of coal and bands 7 ft. 4 in. thick, probably referable to the Tomago Series [123]. In the absence of boreholes of sufficient depth, the southern and south-western limits of these measures are still undetermined. Their northern extension is still uncertain, but Pittman and David admit the

possibility of their coalescing with the Upper Coal-Measures at Rix's Creek, near Singleton.

Beneath these measures there follows the Upper Marine Series, with the last evidence of the glacial action begun in the Lower Marine Series, and continued through the intervening Lower Coal-Measures.

The Lower, or Greta, Coal-Measures

The general description given by Pittman and the details amassed by David present a very complete picture of these measures. They consist of sandstone shales and a characteristic bed of conglomerate usually occurring between the two coal-seams of the series, but occasionally found between splits of the upper seam. Their total thickness ranges only from 120 to 200 ft., yet, from the point of view of quality and productivity, the series, in the 15 miles of country between West Maitland and Cessnock, has become the most important coal-mining district in Australia.

The upper seam varies in thickness from 14 to 32 ft., and the lower seam from 3 to 11 ft. The former was worked for many years prior to 1886 at the Greta and the adjoining Anvil Creek colliery on the western side of the Lochinvar anticline or dome and at Homeville Colliery on the eastern side, but, by far its most important development, between Homeville Colliery and Cessnock, was disclosed in that year by David and his geological survey party. The importance of this discovery, now fully appreciated by colliery companies, is shown by the production from this seam in 1917 being nearly 60 per cent. of the output from the Northern Coal-field.

The coal breaks with a conchoidal fracture, and is somewhat cannel-like in appearance. It is hard, clean, and suitable for gas-making and household purposes. It is a useful steam-coal, but rather fast-burning and smoky; the sulphur content is rather high, particularly in the "brassy tops" of the upper seam, which, on account of their character, are usually left as a roof in the working places, and are consequently lost for ever. The sulphur contents and the cannelly nature of the coal, with a consequent low ignition point, tend to induce spontaneous combustion. These characteristics, further, may account for

the weathering of the Greta coal-seams at their outcrop to an exceptional degree, as the writer has personally observed. David, citing an instance of this, says, "The entire 30 ft. of coal, as it approached the surface, was represented by a few inches of perished coal, or black-peaty clay," and "it has often been found necessary to tunnel for a distance of 80 to a 100 yards before the coal makes its full thickness."

In the "Burning Mountain" at Wingen, 90 miles N.N.W. of West Maitland, the Greta seam has, through spontaneous combustion, been burning for a period of at least 1,000 years according to an estimate by David [126/p. 190], who, in the same *Memoir*, p. 144, states that the Greta seam, in the Cessnock district, has been on fire in prehistoric times along the outcrop for a length of 15 miles.

The outcrop of the Greta measures laps round the Lochinvar dome, from which coal-bearing strata, probably amounting to 9,000 ft., have been denuded. In addition to this barren area there are large portions of country where the steep dip of the measures takes the coal rapidly to an unworkable depth beneath the Middle and the Upper Coal-Measures.

The characteristic bed of conglomerate previously referred to can be traced for over 100 miles from West Maitland to Wingen. Again, in a direct line 160 miles due north of Wingen, at Ashford, south of the Queensland border, there occurs what is probably the equivalent of the Greta Coal-Measures, including a fine, but highly inclined seam 30 ft. thick [126]. Some 400 miles further north, on the Dawson River coal-field, in Queensland, west of Rockhampton, an 11-ft. seam of fine steam-coal, *capped by marine strata*, was discovered by B. Dunstan [128],[1] and described by him as the best steam-coal yet found in Australia. This also is supposed to correspond to the Greta horizon. Again, 200 miles further north, in the Bowen River coal-field, R. L. Jack [130] has described four seams overlaid by marine strata rich in the fossil brachiopod, *Strophalosia*, as are the Upper Marine beds of N.S. Wales. If the correlation of these several occurrences with the Greta measures be correct, the distribution of the latter in isolated patches north of Maitland extends to 900 miles.

[1] Calorific value, 7,763; Evap. power, 2·98.

An immense area south of the Newcastle coal-field probably contains these coals, but at unworkable depths. Only on the Clyde river, 180 miles S.S.W. of Newcastle, are patches of Greta coal again exposed.

In Victoria the Greta Coal-Measures have not yet been found, though possibly their equivalent horizon is the *Gangamopteris* sandstones of Bacchus Marsh. The known Permo-Carboniferous strata of Victoria belong chiefly to the glacial horizon of the Lower Marine Series of N.S. Wales, and David expresses the opinion that "it is not improbable that coal may exist in some part of the extensive concealed areas of the Victorian Permo-Carboniferous rocks." Thin coal-seams of excellent quality, the equivalents of the Greta horizon, occur at Preolenna in the north of Tasmania. Lower Marine glacial beds are found in South Australia, and A. G. Maitland refers the coal of the Irwin river, above Geraldton, Western Australia, to the Greta horizon, in spite of its hydrous character.

IV. Palæozoic—Carboniferous

The physical conditions under which the rocks of Carboniferous age in Australia were laid down differed greatly from those of Permo-Carboniferous times. Fossil, and in places stratigraphical, evidence of a marked break between the two periods exists.

During the earlier period there was intense volcanic activity, accompanied by considerable oscillation of the earth crust, resulting in the elevation of certain areas above, and the subsidence of others beneath sea-level. The advent of the Permo-Carboniferous period coincided with the appearance of the remarkable and widespread glacial conditions common to Australia, South Africa, and north of the equator, to India. New forms of plant and animal life supervened. *Lepidodendron* and the *Rhacopteris* fern, which flourished over Australia, *Phillipsia*, the last Australian trilobite, and many of the contemporaneous brachiopods, became extinct at the end of the Carboniferous period, and the reign of *Glossopteris* and *Gangamopteris* flora in the Permo-Carboniferous age was established.

The Carboniferous strata of N.S. Wales contain no coal

seams of commercial value, so far as known. Near Stroud, 40 miles north of Newcastle, a 5-ft. seam of very inferior stony coal and coaly shale occurs at the top of this system. Similarly, at Irrawang, nearer Newcastle, thin seams, full of bands of clay or volcanic ash, are found. These evidences, and the wide distribution throughout the measures of volcanic dust, lava and volcanic mud render the existence of any clean coal improbable. *Rhacopteris* fern leaves and impressions of *Calamites* are numerous, and form a useful guide in distinguishing the rocks of this system from the Permo-Carboniferous strata.

Analyses of New South Wales Coals

The Samples analysed represent the Coals as sold

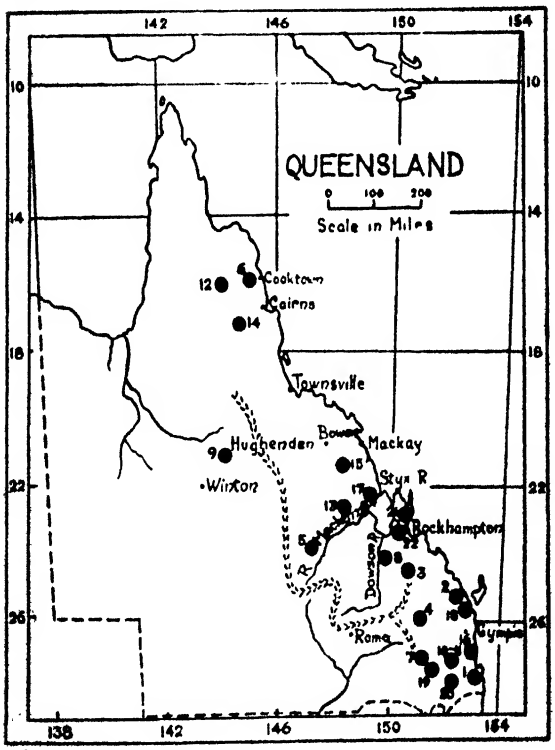
	No. of samples.	Moisture.	Vol matter.	Fixed Carbon.	Ash.	Sulphur.	Specific gravity.	Evap. power.
NORTHERN COAL-FIELD								
Upper Coal-Measures								
Borehole Seam .	36	—	—	—	7·32	—	1·322	12·82
Burwood Seam .	15	—	—	—	8·29	—	—	12·68
All seams . .	78	2·01	36·01	53·27	8·71	0·468	—	12·70
Middle Coal-Measures	5	1·88	35·71	54·77	9·64	1·185	1·350	12·50
Lower Coal-Measures (Greta)	31	1·89	41·35	50·51	6·25	1·014	—	13·20
SOUTHERN COAL-FIELD								
Upper Coal-Measures								
No. 1 (Bulli Seam)	27	—	—	—	10·94	—	—	12·80
No. 2 (4 Foot Seam)	4	—	—	—	12·24	—	—	12·50
No. 3 (Dirty Seam)	4	—	—	—	15·91	—	—	—
All Seams . .	35	0·71	23·65	63·98	11·66	0·470	—	12·00
WESTERN COAL-FIELD								
Upper Coal-Measures (See p. 111.)	25	2·05	32·31	53·08	12·56	0·672	—	11·90

Outputs of Coal for Years 1913–9

Year.	Northern District		Western District.		Southern District.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
		£		£		£
1913 . .	7,402,627	2,892,256	930,066	239,694	2,081,472	638,425
1914 . .	7,113,991	2,734,872	913,890	253,494	2,362,741	749,364
1915 . .	6,307,015	2,397,833	880,595	242,481	2,261,398	784,316
1916 . .	5,311,832	2,406,265	966,396	269,393	1,848,933	660,761
1917 . .	5,380,957	3,074,966	1,070,041	427,667	1,841,869	920,197
1918 . .	5,966,926	3,481,418	1,111,672	481,940	1,984,578	978,449
1919 . .	5,629,253	3,795,244	1,175,727	549,599	1,826,574	1,028,003

Coal Reserves

Based on the assumption that the workable coal extends over an area of 16,550 sq. miles, and is of available thickness only 10 ft., and deducting one-third, E. F. Pittman estimates the available coal within 4,000 ft. depth at 115,346 million tons [2/p. 12].



Queensland

An eminent geologist, when referring in 1872 to the geology of Queensland, stated, "It is doubtful if true Permian and Trias

exist or are represented on the Australian Continent." The reference to "true Permian" probably indicates that doubt which gradually found definite expression in the present indefinite designation, Permo-Carboniferous, for strata in Australia of Permian, and possibly of partly Carboniferous, age.

But, according to B. Dunstan, Chief Government Geologist of Queensland, coal is found in this state in rocks of Tertiary, Cretaceous, Jurassic, Triassic and Permo-Carboniferous age.

The relative age of Queensland coals, as at present understood, is as under, from Tertiary to Triassic [121/p. 4].

TERTIARY:
Waterpark Creek . . . . . Brown coal.
CRETACEOUS (freshwater and marine deposits):
(Upper) Burrum Series (freshwater) . . . . Coal-bearing.
= Winton Series (freshwater).
(Lower) Maryborough Series (marine).
= Rolling Downs Series (marine).
JURASSIC (exclusively freshwater deposits):
Walloon Series . . . . . Coal-bearing.
= Darling Downs Series.
= Tiaro Series
? = Laura (Cooktown) Series.
? = Peninsula Series.
? = Styx Series
? = Stanwell Series [No. 22 on Map].
? Callide Series.
TRIASSIC (exclusively freshwater deposits):
Bundamba Series . . . . . Coal-bearing.
= Landsborough Series.
= Helidon Series
Ipswich Series (Ingalpa, etc.) . . . Coal-bearing.
PERMO-CARBONIFEROUS:
Upper Coal-Measures.
Upper Marine Series.
Lower Coal-Measures.
Lower Marine Series
Loc. Dawson River.
Mackenzie—Central Railway.
Clermont.
Nebo.
Bowen River.
CARBONIFEROUS:
Star Series.
? Lower Gympie Series, etc.

Tertiary Coal-Measures

Waterpark Creek brown-coal area lies 34 miles N.N.E. of Rockhampton, and is the only known brown coal in Queens-

land [135/p. 216]. It occurs in two seams, aggregating 57 ft. in thickness, and, though hydrous (see Table of Analyses), is of good quality. It is still unworked.

Cretaceous Coal-Measures

The most important coal-seams of this series are those of the Burrum coal-field in the coastal district, between 8 and 20 miles from Maryborough, where coal of excellent coking quality is mined. The measures (Upper Cretaceous) rest conformably on the marine beds of the Maryborough Series (Lower Cretaceous), the equivalent of the Rolling Downs Series. These marine beds, which extend over probably 1,200 sq. miles on the eastern coast, are a useful guide to the position of the coal-seams of the overlying and frequently detritus-covered Burrum measures [127/p. 2] [143] [141].

In Central Queensland a stretch of country from north of Hughenden to South of Winton, 200 miles long and 70 miles wide, occupied by Cretaceous rocks (the equivalent of the Burrum Coal-Measures), is known to be coal-bearing. This area is within the great artesian water-basin, and has been extensively bored for water. Some coal-seams have been proved in this way, both at shallow depths and at from 1,000 to 2,000 ft., but little is known regarding them, and it is, moreover, not clear that coal-mining in the water-bearing strata would be feasible. Dunstan mentions that north of Warreah, near the Flinders river and 40 miles east of Hughenden, in a shaft sunk to work a thick seam [139/p. 19], "large quantities of water were struck at 500 ft. and prevented the shaft being sunk to the depth required." He, however, thinks that prospecting for coal in these western districts is warranted, except at points close to and consequently competing with coal of an older series and generally of better quality.

In reference to this district, J. H. Reid, Government Geologist, in his report on the *Glossopteris* beds at Bett's Creek [142], says it is probable that the coal-bearing shales of the Flinders river and the coal-beds found in the Blantyre bore (10 miles north of Warreah), at depths of from 400 to 500 ft., where they lie under shales containing marine Cretaceous shells, belong to

the Permo-Carboniferous or Lower Mesozoic," and "we may reasonably expect to get Permo-Carboniferous beds under the newer formations of the central plains of Northern Queensland." It may be noted that coal in the Westphalian and the Kent coal-fields is worked beneath water-bearing Cretaceous beds—with due precautions. Reid, referring to Bett's Creek *Glossopteris* beds, states, "*Glossopteris* has never been found in other parts of Australasia above the horizon of the Upper Coal-Measures" (Permo-Carboniferous).

Jurassic Coal-Measures

In 1915, Dunstan classified the Walloon Series of the Ipswich district as Jurassic, thus separating it from the Ipswich Coal-Measures and Bundamba Series, which he placed as Triassic [127/pp. 2 and 25]. This classification has been lately supported by A. B. Walkom's examination of the flora of the Walloon and Ipswich measures [133]. Dunstan, at the same time, stated that the old term "Trias-Jura" had, after due consideration, been changed to "Triassic" and "Jurassic" as the names of individual systems.

The important members of these measures, the Walloon Series in the district to the south of Ipswich, and the Tiaro Series west and south of Maryborough, are, with the somewhat doubtful Jurassic measures of the Peninsula, Styx, Stanwell and Callide coal-fields, found in the south-east quadrant of the State. The Laura Series, on the Endeavour Laura and Deighton rivers, to the west of Cooktown, in the far north, is the only outlying area of these measures. But, according to Dunstan [136], the extension of the Walloon Series may be traced from the Macpherson Range, on the southern Queensland border, through Chinchilla and Roma, and along the Great Dividing Range to the extreme north of Cape York Peninsula, a distance of 1,300 miles.

Triassic Coal-Measures

So far as at present determined, the Bundamba Series, with the equivalent Landsborough and Helidon Series, and the Ipswich Series comprise the Triassic Coal-Measures.

Permo-Carboniferous Coal-Measures

The chief coal-resources of Queensland are undoubtedly to be found in these measures, and it is probable that the quantity will eventually be found to be largely in excess of the conservative official estimate.

From a point on the Dawson river, 150 miles west of Maryborough, an area occupied by rocks of this system extends in a north-north-east direction to the Bowen river, and has an average width of 100 miles In this area, equal in extent to nearly two-thirds of England and Wales, coal of excellent quality is exposed at many points, such as the 20-ft. Mammoth seam on the Central Railway in the Mackenzie river area, the 66-ft. seam of the Clermont area in the west, and the 20 to 29-ft. seam of the Bowen area in the extreme north.

Geological mapping of the Bowen river district [137] [135/p. 215] shows the coal-measures to be well defined, resting conformably on a series of beds of conglomerate and agglomerate made up of volcanic material, and overlaid by a great thickness of sandstone, etc., containing abundant marine fauna. These underlying and overlying beds are considered to be the Upper and the Lower Marine Series of the Permo-Carboniferous, in which case the coal-measures are the equivalent of the Lower or Greta Coal-Measures of New South Wales.

In this district about 30 sq. miles of the Upper Marine beds, a very small portion only of the known area, has been examined. The coal-field contains four seams, of which the thinnest varies in thickness from 2 to 6 ft. and the thickest from 20 to 29 ft. The quality of the coal appears in places to have been affected detrimentally by intrusions of igneous rock, but elsewhere it is almost all that could be desired, and, on completion of the railway to the coast, the coal should command a coastal and export market. Recent boring has proved seven seams, of which five are considered workable, and the Mines Department in 1917 recommended the construction of a railway to connect the field with Bowen.

The possible hidden extension of the Permo-Carboniferous measures has been already referred to on pages 119 and 120.

Coal Reserves

Queensland, with its area of 670,500 sq. miles, may be described as a country rich in coal. The chief reserves lie in the south of the State in its coastal and eastern part. The more accessible deposits have been brought under limited contribution, but the bulk still remains little prospected and wholly undeveloped. Nor is this strange in a country with a population of but one person to the square mile. An estimate of coal resources must, therefore, be largely tentative. The official estimate, made apparently on conservative lines, about 1912, is :

	Tons (metric).
Actual Reserve . . .	412,000,000
Probable Reserves . . .	1,085,000,000
Possible Reserve . . .	13,122,000,000

Table of Proximate Coal Analyses *

Nos. on Map	Moisture	Volatile Hydro Carbons	Fixed Carbon.	Ash.	Estimated Calories.
	Range.	Range.	Range.	Range.	
1. Beaudesert Area . .	8·2	30·13	58–13	25–11	6,802
2. Burrum Area . .	5·0·1	31–24	68·62	8–4	8,079
3. Callide Creek . .	12·0·8	28–23	59–41	20–4	7,051
4. Chinchilla Area . .	No reliable analysis				
5. Clermont Area . .	5·0·8	5·7 21	62 53	10–4	7,726
6. Cooktown Field . .	8·0·3	30–19	72–34	26–8	7,249
7. Dalby Area . .	6–5	30 39	42–41	12–13	7,027
8. Dawson River . .	3·1	14–6	80–74	17–4	7,763
9. Hughenden Area . .	15·7	32·18	51·34	31–8	7,060
10. Ipswich Area . .	2·0·7	33·21	72–50	21–4	7,467
11. Ipswich (Walloon) .	8 1	40–23	48–29	25–6	7,096
12. Little River . .	3–1	20–6	83–58	17–6	7,607
13. Mackenzie River (Central Railway) .	3·0·4	24–7	81–43	29–5	8,095
14. Mount Mulhgan . .	—	—	—	—	7,095
15. Nebo (Bee and Walker's Creeks) Area . .	3–2·5	12–8	84–61	16–3	7,314
16. Nundah—Eagle Farm .	0·0·6	35–21	55–39	26–19	7,006
17. Styx River . . .	2–1	31–22	64–59	12–3	8,034
18. Tiaro Area . . .	12–10	34–3	90–39	21–4	7,036
19. Toowoomba Area .	3–5	40–26	42·6–40	17–14	—
20. Warwick Area . .	5–4	44–30	44–37	16–9	6,785
21. Waterpark Creek .	10·7–10·2	41·5–40	43–39	10–6	6,832

Note.—Many other areas exist in the State, but there is no direct evidence of their being actually or probably productive.

The output of coal in 1915 was 1,024,273 statute tons, or 8·3 per cent. of the total Australian output, or 0·082 per cent. of the World's output. The output in 1919 was 931,631 tons.

* For complete table of analysis see [138/p. 262]. For coal bibliography see [39/p. 249] [138/p. 245] [140].

South Australia

The known coal deposits of South Australia are of very limited extent, and their economic value is still doubtful. They are classified as follow:

1. Tertiary. Lignite in the south of the State.
2. Lower Cretaceous. Brown coal and lignite of the Great Australian Artesian Water-basin.
3. Jurassic. Leigh's Creek Coal-field.

I. Tertiary

The lignite of this age found at several places, such as the Adelaide Plains, Noarlunga, etc., has not aroused any interest and is not worked. A borehole on the Paradise Coal Mining Company's property in Section 2,093, Hundred of Yatala, near Adelaide, struck lignite at 150 ft. and proved the seam to be 43 ft. thick. This lignite is high in moisture, ash and sulphur [145].

II. Lower Cretaceous

No coal of a value apparently sufficient to warrant development has been found in these measures, although the presence of small seams of brown coal has been proved in boring for artesian water.

III. Jurassic

Leigh's Creek coal-field consists of two basins adjoining each other, and situated on the Great Northern Railway. Copley Station (formerly called Leigh's Creek) is at the northern end of the southern and smaller basin. It is 373 miles by rail from Adelaide and 163 miles from Port Augusta; Telford station, six miles further on, is within the northern basin [144].[1]

The Coal-Measures occupy irregularly-shaped depressions in Cambrian slates. The northern basin has a length of 9 miles from north to south, a maximum width of 5 miles, and an

[1] This Review rectifies certain details supplied to *The Coal Resources of the World*, and gives the results of more recent investigations.

area of 36 sq. miles. The southern basin is 4 miles long, with a maximum width of 2 miles and has an area of 6·4 sq. miles. The strata in each basin dip towards the centre.

Exploratory work in the coal-field has, with the exception of an old shaft sunk to 70 ft. in the southern area, been confined to the northern basin, and consists of four boreholes, an 11 ft. by 6 ft. shaft, and certain underground workings in the main coal-seam, at a depth of 300 ft. The coal, which at the shaft is 45 ft. thick, is of a hydrous character, and the recently suggested term, "sub-bituminous," may be applied to it.

The depth and thickness of the seam, where proved, are as under:

Depths.	No. 1 Bore.	No. 2 Bore.	No. 3 Bore.	Shaft.
Top of seam . .	125	1,107	608	240 ft.
Bottom of seam . .	158	1,545	646	285 ,,
Thickness of seam .	33	48	38	45 ,,

The quantity of coal extracted prior to 1909 was 12,455 tons, and a further 713 tons were won in 1917, when a thorough sampling of the coal was undertaken by the Department of Mines. There was no production in 1918. Analyses of the numerous samples gave the following general results:

Average of Undried Samples

	Water at 105° C.	Volatile matter.	Fixed Carbon.	Ash.
From top 7 ft. . . .	32·35	26·00	34·42	6·83
From full thickness (45 ft.)	27·15	25·24	33·68	13·91

Average of Air-dried Samples

	Water at 105° C.	Volatile matter.	Fixed Carbon.	Ash.	Sulphur.
From top 7 ft. . . .	16·46	30·03	44·68	8·20	0·37
From full thickness (45 ft.)	14·23	27·75	41·75	16·25	0·24

The samples on being air-dried lost practically half their moisture. The best coal is obtained from the top 6 ft.

The coal in general is dull, with layers of bright lustrous coal. Occasional bands of clayey matter, seldom over half an inch thick, and without continuity, blend gradually with the coal. The bands were included in the samples taken, as from

their mode of occurrence, it would be difficult to separate them from the coal by hand-picking.

The coal may be classified as sub-bituminous, and as usual with coal of a hydrous character, is peculiarly liable to crumbling on exposure to the dry air and strong sunshine. No improvement in this respect can be expected in the coal occurring at a greater depth.

The economic value of this coal-field has hitherto been in considerable doubt, but, when regard is had to the large quantity of coal contained, and the fact that all the coal used in the State is imported, a thorough and continued investigation is fully justified. The whole of the coal practically can be safely extracted if the method of hydraulic packing of the spaces left as the coal is removed in horizontal sections from downwards be adopted. To attempt mining a deposit of this thickness and character by any other method is to court disaster. The utility of this system of packing has been amply demonstrated in Germany, and an admirable application of it under Government control is found in the working of a 27-ft. seam at Ombilin Mine, near Padang, on the west coast of Sumatra. The general conditions of Leigh's Creek coal-field are such that its resources can only be fully utilized if worked as a State asset, though not necessarily by the State.

Tasmania

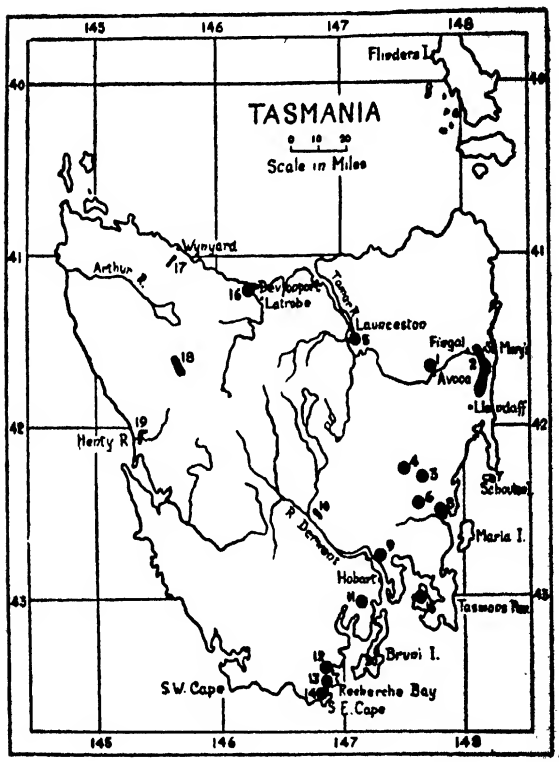
Tasmania is a country of many small coal-fields. The irregular contour of its surface, largely covered with heavy timber, and often with dense undergrowth, while lending it a peculiar charm, renders difficult the discovery of its mineral resources. The conditions under which the coal-measures occur are geologically interesting, but commercially of a limited character.

The coal-bearing measures belong to the following geological periods:

I. Kainozoic. Brown coal or lignite.

II. Mesozoic. Bituminous coal; Upper Coal-Measures of *Tasmania*.

III. Palæozoic. Bituminous coal and kerosene shale; Permo-Carboniferous, or Lower Coal-Measures of *Tasmania*.



Certain distinctive features relating to the coal-measures are recognized in Tasmania, as. for example:

1. The absence of strata corresponding to those referred in New South Wales to the Carboniferous system.

2. The existence of "tillite" and glacial conglomerate at the base of the Permo-Carboniferous Coal-Measures, corresponding to the glacial beds of Australia, India, South Africa, etc.

3. The presence of plants in the Mesozoic Coal-Measures, linking these with the Trias-Jura [1] beds of Australia, India, South Africa, etc., and the absence, as pointed out by W. H. Twelvetrees, of *Tæniopteris Daintreei*, the critical plant of Australian Jurassic rocks [153/p. 12].

4. The occurrence of diabase, now generally considered as of late Mesozoic age, which pierced the Permo-Carboniferous and Mesozoic strata, and forced its way between the beds as an intrusive sheet now found in exposures over half the country.

5. Much step-faulting, breaking the continuity of the coal-measures and producing mining areas of small extent.

The general review of the coal-fields of Tasmania given by Twelvetrees in *The Coal Resources of the World* is here largely drawn on. Additional information is drawn from Bulletins of the Geological Survey of Tasmania.

I. Lignite and Brown Coal

Tertiary lignite and brown coal are widely distributed, and are found at George Town, Rosewears, Muddy Creek, Evandale, Kimberley, Sassafras, Howth, Blythe River, Detention, Magnet, Henty River, Macquarie Harbour, Glenora, Ouse Bridge, etc. They are at present of no economic value.

II. Mesozoic Coal

Although some of the following coal-fields are scarcely separate basins, the divisions adopted in Twelvetrees' review are here adhered to.

[1] It is probably an error to refer these Trias-Jura beds, as is done in this Monograph, to the Clarence-Talbragar Series of N.S. Wales, for the Clarence Series, in which *Tæniopteris Daintreei* is plentiful, are more recent than Trias. They may, however, be coupled with the lacustrine fish-beds of Talbragar, but not with the *Glossopteris*-bearing beds of Talbragar, which are Permo-Carboniferous.

Northern and Eastern Fields.

(*a*) Mount Rex
(*b*) Rigney's Seams } Avoca Field.
(*c*) St. Paul's Seams
(*d*) Mount Nicholas Range and Fingal Basin
(*e*) Thompson's Marshes
(*f*) Llandaff-Seymour
} These areas may be regarded as one coal-field.
(*g*) York Plains.
(*h*) Mike Howe's Marsh.
(*i*) Longford.
(*j*) Colebrook.
(*k*) Schouten Island.
(*l*) Spring Bay and Prosser's Plains.

Southern and South-Eastern Fields.

(*m*) Compton and Old Beach.
(*n*) Lawrenny-Langloh.
(*o*) Sandfly.
(*p*) Ida Bay.
(*q*) Hastings and Southport.
(*r*) Recherche Bay.
(*s*) Tasman's Peninsula.

(*a*) *Mount Rex* [No. 1 on Map].—Five miles N.W. of Avoca two seams outcrop on the flank of sandstone hills capped with diabase. The upper seam is reported to be 6 or 7 ft. thick, but the quality has not been determined. The second seam, 100 ft. lower, is about 12 ft. thick, with four clay bands totalling 10 inches. A sample from the second seam assayed:

Seam.	Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.	Coke.
Upper part .	1·2	35·0	54·5	8·5	0·8	Firm
Lower part .	1·7	28·2	55·0	15·1*	—	Firm

* Portion of the bands were probably included.

This is an excellent coal, similar to that of Mount Nicholas, which, however, has more moisture and does not coke. It had not been worked up to the end of 1917.

(*b*) *Rigney's Coal-Seam* [No. 1 on Map].—A seam of excellent coal, 10½ ft. thick, outcrops on the Northern side of the diabase-

covered hills near Avoca on the north of the railway. It differs from Mount Rex coal only in having 26 per cent. of fixed carbon.

(*c*) *St. Paul's Coal-Seam* [No. 1 on Map].—Seams outcropping on St. Paul's Dome, near Avoca, have been prospected above Brookstead, but no information regarding their character is available.

(*d*) *Mount Nicholas Range* [No. 2 on Map].—As already noted, this and the two following areas may be regarded as one field. While a correlation of the seams may be difficult to effect, analysis of the respective coals indicate a distinct similarity.

The Cornwall and the Mt. Nicholas collieries, on the range between the townships of Fingal and St. Mary's, produce about 95 per cent. of the Tasmanian output. Six or seven seams are known, varying from 3 to 10 ft. thick, but mining is confined to two seams known as the "upper," 4 ft. thick, and the "lower," 6 ft. thick, the latter being the chief producer. The coal is non-coking, and an average analysis is:

Moisture.	Vol. matter	F.C.	Ash	Sulphur.
6·16	26·99	57·48	9·13	0·55

(*e*) *Thompson's Marshes*; (*f*) *Llandaff-Seymour* [No. 2 on Map].—These areas extend southward along the east coast from St. Mary's to Llandaff. Several workable seams, said to be of very fair quality, have been proved, and coal is mined at Dalmayne, 8 miles south of St. Mary's, where a colliery has been recently opened up by adits 1,000 ft. above sea-level, and connected by a self-acting aerial ropeway with the sea, at Picanini Point.

(*i*) *Longford Area* [No. 5 on Map].—A seam, 3 to 4 ft. thick, at a depth of from 20 to 70 ft., has been mined to a small extent a few miles south of Launceston. It assays: Moisture, 13·0; Volatile matter, 27·3; Fixed Carbon, 47·1; Ash, 12·6; Sulphur, 0·55.

Coal also occurs at Deloraine.

(*g*) *York Plains* [No. 3 on Map]; (*h*) *Mike Howe's Marsh* [No. 4 on Map]; (*j*) *Colebrook* [No. 6 on Map]; (*k*) *Schouten Island* [No. 7 on Map]; (*l*) *Spring Bay and Prosser's Plains* [No. 8 on Map].

These areas are of small extent, [illegible] are generally thin and of no special value, the coal is only of local interest. The coal of York Plains is rather anthracitic, and is used in malting and other industries.

(*m*) *Compton and Old Beach* [No. 9 on Map].—A few miles north of Hobart and east of the Derwent river, a seam, 2 ft. thick and dipping westerly, occurs at water-level. No information as to quality is available.

(*n*) *Lawrenny-Langloh* [No. 10 on Map].—Between the junctions of the Clyde and Ouse rivers with the Derwent at Langloh Park, near Hamilton, useful coal was many years ago found in a seam variously reported to be 3½ and 5 ft. thick. Diamond drilling, in 1892, proved nine seams in a depth of 282 ft., aggregating from 7 ft. 3½ in. to 13 ft. 2½ in. of coal. No. 1 seam was from 2 ft. 1½ in. to 4 ft. and No. 2 from 2 ft. 6 in. to 4 ft. 7½ in. thick. The beds dip to the west. The compositions of the coals of these seams are:

Seams	Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.
No. 1 . .	0·40	21·27	52·95	15·80	0·58
No. 2 . .	5·30	25·60	53·87	14·20	1·03
Shaft . .	4·00	23·50	66·30	6·20	—

The coals are non-coking, strong, dull and suitable for steam and house purposes, and probably underlie 600 acres.

(*o*) *Sandfly* [No. 11 on Map].—This field is about 15 miles S.W. of Hobart on the divide between the Huon and the North-West Bay rivers. About 1,500 ft. above sea-level outcrops of apparently a dozen seams, at least, occur, but, owing to the frequency of faults, mining operations have practically ceased. The main seam consists of 5 ft. of top coal and 4 ft. of bottom coal, separated by 4 ft. of fireclay; the analyses of the coals of the sections are:

	Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.	
Top section	2·05	27·05	53·70	16·60	—	Coke firm
Bottom section	2·50	25·70	56·00	15·00	0·70	and coherent

The quality is varied, the ash at times increasing greatly and at others decreasing to 9 per cent.; when the latter, the coal is excellent for general purposes. At the eastern end of the range the coal seams become anthracitic, and a 3½-ft. seam contains: Volatile matter, 8; Fixed Carbon, 80·8; Ash, 9 per cent.

Strathblane Colliery [153/pp. 47–55].—This area, not mentioned in Twelvetree's list, lies 32 miles south of Hobart at the head of Port Esperance. A two-foot seam of hard, dense coal, breaking with a cubical fracture and dipping 19° N.E., assays: Moisture, 3·7; Volatile matter, 26·0; F.C., 55·1; Ash, 15·2. Another seam, possibly distinct from the preceding, 2½ to 5 ft. thick and dipping 25° to 30° N.E., shows a massive shining coal of which the following analyses are published:

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.
5·6	30·2	55·2	7·9	1·1
3·6	27·9	55·6	12·9	—

The extent of the area is unknown.

(*p*) *Ida Bay* [No. 12 on Map]. This indentation of Southport Bay is about 45 miles south of Hobart [153/pp. 40–5]. Two seams found are proposed to be used locally for the manufacture of cement. The upper seam is reported to be 6 ft. thick, with a dip of 7° S.W. The coal is dull in appearance, with a few shining layers in it, resembling York Plains coal, and assays:

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.
3·10	12·30	69·20	14·74	0·60

The lower seam, about 100 ft. below the upper, is 5 ft. thick, and consists of massive, rather soft and dull coal, with occasional bright layers:

Analyses

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.	
3·80	28·90	55·50	11·80	—	Govt. Analyst.
2·80	14·00	67·30	15·90	—	ditto.
1·54	15·56	64·90	17·55	0·45	Evap. power 12·2 (Willcoxson)

Note.—This evaporative power is probably overstated.—J. H. R.

(*q*) *Hastings and Southport* [No. 13 on Map].—In the forties of last century the Government carried out exploratory work on Southport Bay, but this and other efforts up to 1915 have disclosed no seams of practical value.

(*r*) *Recherche Bay* [No. 14 on Map].—At Moss Glen, near the mouth of the Catamaran river, seams from 4½ to 5½ ft. thick were discovered in 1900, but have not been developed. The quality is stated to be varied and the ash high [153/p. 21].

South of Moss Glen, the Catamaran main seam, also discovered in 1900, is very varied in thickness, but may average 10 or 11 ft., of which 6 to 9 ft. consists of good coal. Two typical analyses, made by the Mines Dept., are:

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.	
3·0	24·9	61·2	10·1	—	
2·2	24·7	69·3	3·8	0·8	Evap. power, 12·43

(5) *Tasman's Peninsula.*—One or two seams of inferior coal, west of Altwater river in the northern part of the peninsula, were worked by the Imperial Government many years ago.

III. Permo-Carboniferous Coal

The Permo-Carboniferous rocks found in Tasmania are the equivalent of the lower portion of the system which in New South Wales comprises the Upper Marine Series, the Lower (or Greta) Coal-Measures and the Lower Marine Series. Their maximum thickness probably does not exceed 2,500 ft. The fossils of the marine beds are mostly common to both divisions. The plants identified in the coal-measures are *Glossopteris, Vertebraria, Gangamopteris, Næggerathiopsis, Phyllotheca*; the remains of a small amphibian have also been found.

Permo-Carboniferous coal occurs in the following areas:

1. The Mersey and Don Coal-field.
2. The Preolenna Coal-field (Wynyard District).
3. The Western Highlands Coal-field.
4. The Henty River Coal-field.
5. The Mount Cygnet and Bruni Island Coal-field.

(1) *Mersey and Don* [No. 16 on Map].—This field is situated on the north coast, near Devonport, and contains seams of coal from 16 to 20 inches thick, which have been worked on a small scale intermittently for over 60 years for local requirements. The coal has nearly 13 per cent. of moisture and an excess of sulphur.

(2) *Preolenna* [No. 17 on Map].—The following details are taken from Bulletin No. 13, in which Hills fully describes the geology of the field [151].

At Wynyard the basal glacial conglomerates (see following section) only are exposed on the beach. They extend S.S.E. for 13 miles beneath Tertiary sediments and basalt, with an occasional outcrop, till the higher country around Preolenna is reached. Here the following succession of rocks in descending order is found:

		Ft.
Upper Marine Series	Yellow to reddish-brown sandstones unfossiliferous	550
	Sandstone, pebbly sandstone, and mudstone, with marine shells	50
Lower, or Greta Coal-Measures	White, yellow and black sandstones, with coal seams	140
Lower Marine Series	Mudstones, with marine fossils	140
	Blue-grey mudstone, with bands of mudstone conglomerate, unfossiliferous, over	300
	Glacial conglomerate, estimated	1,220

The average dip of the series is 14° to W. or W.N.W.

Of this interesting assemblage the most striking member is the glacial "tillite" at the base. In the consolidated boulder clay, excellent specimens of striated boulders of the older rocks, up to 3 tons in weight, are to be found. The homologues of this tillite are the glacial conglomerates of Bacchus Marsh, and of New South Wales, and, still further afield, the Talchir conglomerate of India, the Dwyka conglomerate of South Africa, the Orleans conglomerate of Southern Brazil, etc.

The seams of Preolenna are very thin, but four, with perhaps another, are possibly workable. One at "9th mile" contains kerosene shale, and another separate seam at Preolenna Creek also includes some of this oil-shale. Two seams are 2 ft. thick and other two are 15 inches. One of the seams contains, over part of the area, kerosene shale from 6 to 14 inches thick.

A comparison of the better coals and the oil-shale with black cannel from other countries is given in the following analyses:

	Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.	Ratio of Vol. matter to Fixed Carbon.
Preolenna coal	1·0	44·7	48·2	6·1	Nil	0·93 : 1
Preolenna shale	1·3	69·56	26·54	2·88	Nil	2·70 : 1
Blaik Cannel						
Scotland	—	40·14	40·36	19·50	—	1·0 : 1
Ohio	—	40·07	41·40	14·53	—	1·06 : 1
New South Wales	—	36·29	36·81	26·90	—	1·00 : 1

Hills classifies the Preolenna coal as "sapropelic" coal,[1] as distinguished from humic (bituminous) coal, and inclines to refer to it as "black cannel." It is interesting to note that the Greta coal of N.S. Wales is slightly cannel-like, with a ratio of volatile matter to fixed carbon of 0·818 to 1, and that patches of kerosene shale have been found in it.

The evaporative power of the coal (exclusive of shale) is 13·9, equivalent to a calorific value of 7,464 calories. Sulphur is usually absent.

The estimated quantity of available coal is 5,000,000 tons.

(3) *Western Highlands* [No. 18 on Map].—Barn Bluff and Mt. Pelion Coal-Measures lie midway between the Mersey and Don coal-field in the north and Macquarie Harbour in the west, and are chiefly interesting from the occurrence there of scattered blocks, from 8 to 12 inches thick, of a black cannel or kerosene shale, known as *Pelionite*. The seam from which these were shed has not been located. West of Lake St. Clair there is a 2-ft. seam with 12 to 18 inches of cannel coal or kerosene shale, which is readily ignited by a match, but little is known about it.

(4) *Henty River* [No. 19 on Map].—Between Zeehan and Strahan insignificant seams on the same horizon as those of the Mersey basin have been found.

(5) *Mount Cygnet and Bruni Island* [No. 20 on Map].—West of D'Entrecasteaux Channel, near Gardner's Bay, a seam, 3½ ft. thick, is mined in a small way. The coal has 22 per cent. of ash and burns slowly. In Adventure Bay, South Bruni, a 2-ft. seam is known to occur.

The output of Tasmanian coal in 1919 was 66,253 tons, valued at the pit's mouth at £47,004.

[1] A term used by Potonié, who regards this class of coal as derived from a gelatinous slime resulting chiefly from the maceration and decomposition of algæ in stagnant water, and forming a matrix in which less destructible organs, such as spores, pollen, etc., were embedded. On this subject see publications by Renault and Bertrand [146] [147] [149] [150], E. A. N. Arber [93], David White [155], J. E. Carne [148], E. C. Jeffrey [152].

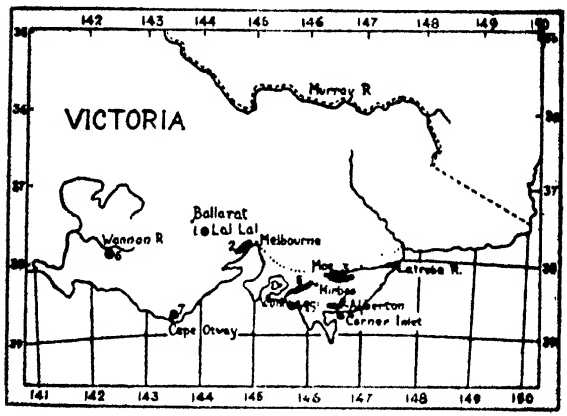
Coal Reserves

The probable reserves are :

	Tons.
Mesozoic coal	54,800,000
Permo-Carboniferous coal . .	11,000,000
Total	65,800,000

Victoria

Victoria is not rich in coal. Beds of lignite, sometimes of extraordinary thickness, are found in Tertiary formations,



and a few seams of bituminous coal, generally thin and of no great lateral extension, occur in Jurassic strata. All are confined to the southern part of the State.

Lignite

Numerous small beds of lignite exist in many parts of Victoria, but the chief deposits are found at Lal Lal, 13 miles S.E of Ballarat, Altona-Laverton and the Werribee Plains west of Melbourne, Morwell in the Latrobe Valley of Central Gippsland, and Allerton near Port Albert in Southern Gippsland.

Lal Lal [No. 1 on Map].—Coal was won here over 50 years ago, and small quantities are still being produced. The deposit has a probable area of three square miles, and boring has proved the coal to be at least 200 ft. thick in places, with a probable average of 80 ft. The average overburden is 60 ft. thick. The quality is undetermined, except where mining has been carried out.

Altona-Laverton [No. 2 on Map].—The seam of lignite in this area, trending south-west, is supposed to extend from the outskirts of Melbourne to beyond Werribee Park, a distance of 10 miles. Its lateral extension inland and seaward is still unproved, but it doubtless continues far under Hobson's Bay.

The thickness and depth at various points are as under [158]:[1]

	Depth to top of seam.	Thickness of seam.
	Ft.	Ft.
Newport	242	14
Altona	348	74
Laverton	356	140
Werribee Park . . .	521	30

Latrobe Valley, Gippsland [No. 3 on Map].—The Latrobe Valley deposits stretch eastward on the line of the main Gippsland railway for a distance of 30 miles, from Yarragon to beyond Traralgon, and extend in width from a mile or two to 20 miles, with occasional spurs to the north and south.

The coal-bearing strata show evidence of general disturbance and much faulting, and the coal occurs, in consequence, at erratically varying depths. Thus, near Morwell, and northward, it is mostly shallow and available by opencast working; between Morwell and Traralgon the cover is from 460 to 490 ft. thick; while from 3 to 4 miles south and south-east of Traralgon the cover is from 25 to 60 ft.

As already mentioned, the thickness of the coal deposits is, in places, remarkable. In No. 1 Bore, close to Morwell, an aggregate of 809 ft. of coal was proved in a depth of 1,019 ft.; 4 miles north-east, in bore No. 2, parish of Maryvale, 453 ft. of coal were passed through in 1,358 ft.; similarly, a mile and a half south of the latter bore, 456 ft. of coal were found in 1,110

[1] This is the latest and most complete report on the Victorian deposits.

ft. The coal-bearing beds had not been bottomed in any of these bores, and more coal may exist beneath.

Allerton, Southern Gippsland [No. 4 on Map].—Near the south coast, in the district between Hedley and Gelliondale, and for a distance of 5 miles alongside the Melbourne–Port Albert railway, a bed of lignite from 120 to 280 ft. thick, with an overburden of from 35 to 95 ft., has been proved. Four miles south of Hedley, and a mile and a half from Lewis Channel, a seam, 207 ft. thick, was struck at a depth of 276 ft. [156].[1] The coal area extends 10 miles westward from Hedley, but the deposits become thin, and are at a depth of from 250 to 380 ft.

Much boring is still necessary in these lignite districts, particularly in Gippsland, to determine their approximate extent and value.

H. Herman, Director of the Geol. Survey, Victoria, has made the following estimate [157]:

	Approximate area	Probable average thickness of coal.	Approximate overburden.
	Sq. mile	Ft.	Ft.
Lal Lal . .	3	80	(60 (average)
Altona Laverton .	200	50	200 to 400
Morwell . . .	700	50	Surface to 500
Hedley–Gelliondale .	300	50	45

He adds, "In many parts of the above areas more than a 50 per cent. extraction will probably not be made." Possibly this is correct, but it is an admission of wasteful methods of mining which the poverty of the State in fuel resources should surely preclude.

The Victorian lignite, or brown coal, as it is termed locally, consists of a yellowish-brown to black matrix, brown when powdered, composed of pollen grains, spore cases and other decomposed vegetable matter, with sporadic inclusions of fragments of trees, the woody fibre of which is still preserved. The moisture of freshly-mined coal generally exceeds 50 per cent., but by air-drying this may be reduced to from 25 to 35 per cent. Continued exposure causes shrinkage, with consequent fracturing and crumbling.

[1] The Annual Report of the Secretary for Mines, Victoria, for 1917, gives full details of this and other bores.

The following analyses quoted by the Advisory Committee have been compiled from various sources:

Proximate Analyses

	Lal Lal.	Altona.[b]	Morwell.[a]	Gelliondale.[a]	Dean's Marsh.[b]	Narracan.[a c]
Moisture	56·78	46·80	53·00	59·60	40·06	41·36
Volatile Hydrocarbons	21·01	27·60	24·00	21·50	26·65	27·13
Fixed Carbon	20·03	20·50	21·80	17·30	30·73	23·26
Ash	1·58	5·10	1·20	1·60	2·56	8·25
	100·00	100·00	100·00	100·00	100·00	100·00

[a] Bore coal.
[b] Partly air-dried.
[c] Much of the Narracan coal is low in ash.

Ultimate Analyses of Coal dried at 105° C.

	Morwell. Per cent.	Altona. Per cent.	
Carbon	60·5	61·59	
Hydrogen	4·4	4·17	
Oxygen	25·5	25·00	(approx.)
Nitrogen	0·8	0·63	
Sulphur	0·3	0·04	
Ash	2·5	8·01	
	100·00	100·35	

Mahler bomb determinations of Morwell coals from open-cut workings

	1.	2.	3.	4.	5.
Moisture as determined at 105° C.	35·0	44·0	45·3	46·0	45·4
B.T.U.	7,518	6,756	6,857	6,136	6,233
Calories	4,699	4,222	4,286	3,835	3,895
Evaporative Power	7·77	6·98	7·09	6·34	6·44

Note.—In coal air-dried to 22·5 per cent. moisture, the average calorific value = 8,840 B.T.U.

Reserves of Lignite

It is still impossible to estimate accurately the available quantity of lignite in Victoria, but it would appear that the estimate of 30,000,000,000 tons, given by the staff of the Geological Survey, is a safe computation.

The various problems connected with the utilization of these deposits for the supply of electricity to Melbourne and other

places are fully discussed in the report of the Advisory Committee. The opinion expressed (in 1917) is that power generated alongside the Gippsland "brown coal" deposits could be transmitted to Melbourne, a distance of 82 miles, and sold to existing power-houses at about 0·326*d.* per unit.

Bituminous Coal

The deposits of coal, other than lignite, in Victoria are very limited in extent, and are confined to Jurassic strata in southern Gippsland [No. 5 on Map], the Otway Ranges [No. 7 on Map], and the Wannon river [No. 6 on Map], all in the southern part of the State. The only seams of any importance, hitherto found, are in southern Gippsland, in a belt running from S.W. to N.E. through Kilcunda, Wonthaggi (Cape Paterson), Outtrim, Jumbunna, Mirboo, and Coalville (Moe) [No. 5 on Map]. They range in thickness from 2 ft. to 6 ft., and in one case at Wonthaggi reached 9 ft. 10 in., but, as a rule, they are thin. In this regard it may be noted that the average of Belgian seams worked is not over 2 ft., and a seam of smithy coal, 11 inches thick, has long been worked in Scotland. Numerous faults and the great and rapid variation in the thickness of the seams add considerably to the cost of mining.

Extensive boring has been carried out at State expense for many years in search of coal of workable thickness, and the expense has been justified by the steadying effect which local production has exerted on the price of imported coal. Boring is also used at the Wonthaggi "State Mine," where a series of bores precedes the mine workings in order to prove the position and thickness of the coal in these irregular measures.

The explorers, Hovel and Hume, as early as 1825-6, discovered coal at Cape Paterson, but even in 1888 the writer, when visiting the district, found that only one small mine at Coalville, near Moe, had begun operations. A few years later, companies began work at Korumburra, Jumbunna and Mirboo, and since then have had a career useful to the public, but rather unremunerative to themselves.

At the end of 1909 the State Mine at Wonthaggi was begun, and up to the end of 1917 had produced 3,490,628 tons of coal

of a value of £1,646,052 at the pit's mouth. The outputs of the various mines for 1917 were as under:

	Tons (2,240 lb.).	Value at pit's mouth.
State Mine, Wonthaggi . .	405,498	£283,848
Jumbunna	22,236	19,028
Powlett North, Woolamai .	20,149	16,119
Austral	13,888	13,092
Sunbeam	2,491	1,837
Coal Creek	1,958	1,335
	466,220	£335,259

The output for 1918 was 505,775 tons.

The following analyses are typical of Victorian coal [157/p. 31]:

	Moisture.	Vol. matter.	F.C.	Ash.	Calories.
State mine, average of 3 samples . . .	6·91	28·31	55·53	9·24	6,666
Outtrim, Austral and Jumbunna. . .	4·88	29·71	59·97	5·73	7,181

Victorian coal is unsuitable for gas or coke making, but is highly valued as a house coal.

Coal Reserves

The erratic thickness and sporadic nature of the seams render an estimate of reserves, other than those actually proved, a matter of conjecture. The Department of Mines in 1912 estimated the Actual Reserves of coal in seams over 1 ft. thick to a depth of 4,000 ft. at 15,150,000 tons. This represents 30 years' life at the present rate of production.

Western Australia

In measures of Post-Tertiary and Jurassic age beds of lignite and brown-coal, generally inferior in quality, have been found at various places throughout the State. Little work has been done on them, and, in the absence of geological surveys, no estimate has been made of the possible quantity of this class of coal.

Coal of marketable quality has been, so far, found only in one comparatively small basin, the Collie coal-field, in rocks of Carboniferous age. Strata of the same age are also widely

distributed throughout the State, as in the far north of the Kimberley Division and the western mid-coastal districts of the Gascoyne and the Irwin rivers.

Towards the base of the Permo-Carboniferous rocks of the Gascoyne district there occurs a persistent boulder bed composed of striated pebbles and boulders of granite, embedded in a calcareous fossiliferous matrix, which contains fragments of *Spirifera*, *Productus* and *Polyzoa*, in addition to *Aviculopecten tenuicollis* [159]. This glacial boulder bed, known as the Lyons Conglomerate, has been proved to extend for a distance of 200 miles, and may be assumed to be the equivalent of the glacial beds towards the base of the Lower Coal-Measures of New South Wales; of the Preolenna Coal-Measures of Tasmania; and of the boulder beds of Bacchus Marsh, in Victoria.

Similarly, in the Irwin river district, a zone of argillaceous limestone containing striated boulders occurs about the middle of the Permo-Carboniferous series. The coal of inferior quality discovered in this district many years ago is found in rocks higher in the series.

Collie Coal-field.—This field lies in the south-western corner of the State, 100 miles south of Perth and 25 miles east of Bunbury. The country is thickly timbered with hardwood (Eucalyptus) trees, which attain a remarkable size considering the layer of sand and gravel soil that thinly covers the rocks. The Government, on the advice of J. R. M. Robertson, of Sydney, began boring in 1892, and several workable seams of coal were soon located.

The Coal-Measures occupy a roughly oval-shaped depression in the surrounding granite, schist and other crystalline basement rocks, and have an approximate area of 95 sq. miles, according to H. P. Woodward [161], and 50 sq. miles, according to Gibb Maitland [160]. Faults bound the field on all but one side, that on the south-western side having an estimated downthrow to the north-east of at least 2,000 ft. The preservation from denudation of this remnant of coal-measures, which probably extended over a wide area, is undoubtedly due, as in the case of the important Damuda river coal-fields of India, to this block-faulting in the crystalline rocks. (See *India*, p. 49.)

The Coal-Measures consist of *Glossopteris*-bearing beds of shale, alternating with sandstone and grit, all sprinkled with mica. The general inclination is 1 in 17 to the south.

In the main portion of the field the following seams occur in descending order:

Cardiff No. 1 Seam	9 to 12	ft. thick
Cardiff No. 2 (or Boulder) Seam	7	„ „
Collieburn No. 1 Seam	9	„ „
Collieburn No. 2 Seam	6 to 8	„ „
Coal (no name)	8	„ „
Proprietary No. 1 Seam	4 to 8	„ „
Proprietary No. 2 Seam	5 to 7	„ „
Wallsend Seam	9 to 17	„ „

Another series of seams discovered in the north-east corner of the field would appear to be lower beds. With the omission of seams under 3 ft. in thickness, they are found in descending order, as follows:

Coal, 3 ft.; coal, 4 ft.; coal, 6 ft.; coal, 6 ft. 4 in.; coal, 5 ft. 4 in.; coal, 4 ft.; and coal, 5 ft.

According to Gibb Maitland, it has been estimated that, exclusive of seams of trifling thickness, the total thickness of coal is about 137 ft. in the 2,072 ft. of strata so far explored.

The Collie coals consist of alternating bands of splinty and bright coal separated by layers of soft charcoal, the so-called "mother of coal." The coals are hydrous, semi-bituminous, and non-caking, and, though hard, tough and unfractured when mined, they rapidly develop cracks on exposure and tend to disintegrate with the formation of an undesirable amount of slack. They burn slowly, with little smoke and a short flame, to a light, bulky and light-coloured or reddish ash, free from clinker.

Woodward quotes the following mean analyses obtained from numerous samples taken from the coal face:

Proximate Analysis

Moisture	21·18
Volatile Hydrocarbons	28·99
Fixed Carbon	43·73
Ash	6·10
	100·00
Specific gravity	1·349

Ultimate Analysis

	Fresh Coal.	After deducting moisture.
Carbon	54·51	69·80
Hydrogen	3·46	4·43
Oxygen	13·23	17·00
Nitrogen	1·07	1·37
Sulphur	0·53	0·68
Ash	5·28	6·72
Moisture	21·92	—
	100·00	100·00
Calories	5,354	6,705

(Analyst) E. S. SIMPSON.

On exposure for a month to the warm dry atmosphere common to this region the coal seems to lose over 7 per cent. of the sample weight or one-third of its initial moisture, and has consequently an increased calorific value. During locomotive trials made with this coal in 1905 the following results were obtained: Calories, 5,817; Moisture, 13 per cent; Ash, 6 per cent. The percentage of moisture in the freshly-won coal is remarkably high for a coal of Permo-Carboniferous age. Coal found at a place called Wilga was determined in 1919 to be of similar character to ordinary Collie coal, but not equal in quality to the best Collie coal. It indicates, however, the possibility of finding coal outside of the small Collie basin.

Coal Reserves

In 1911 the available coal from six of the known seams, ranging from 6 to 17 ft. thick, was estimated at 310,000,000 tons. In the same year, H. P. Woodward, in his contribution to *The Coal Resources of the World*, estimated that of 24 seams from 3 to 17 ft. thick, there were:

	Tons.
Actual Reserve	153,331,200
Probable Reserve	500,000,000

The output of coal from the Collie field in 1918 was 337,039 tons.

New Zealand

In 1866, when information regarding the coal deposits of New Zealand was still scanty, James Hector adopted the simple and practical classification of the coals as *hydrous* and *anhydrous*. The large development of hydrous coal in the country justified the expedient, and, following this method, we find the workable coals of these classes distributed in the following localities according to Hector's classification:

Hydrous.—(Coal containing 6 per cent. or more of permanent water.)

1. Lignite . . . *South Island.* Central Otago and Southland.
2. Brown Coal . . *South Island.* Shag Point, Green Island, Kaitangata, Nightcap of Southland; all in Otago.
   North Island. Waikato basin, south of Auckland.

Anhydrous.—(Coal containing less than 6 per cent. of permanent water.)

3. Pitch Coal * . . *North Island.* Kawakawa, Whangarei, Hikurangi, Ngunguru, north of Auckland. Mokau-Awakino, south of Auckland.
4. Bituminous Coal . . *South Island.* Collingwood and Pakawau, in extreme north. Buller-Mokihinui and Greymouth, on west coast.

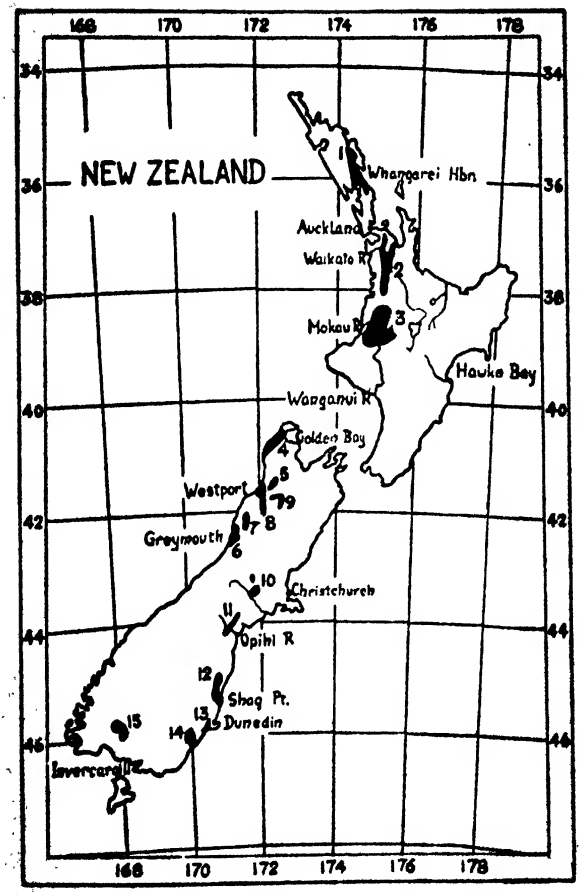
To these has to be added semi-anthracite in the Paparoa Range, Greymouth.

* Pitch coal varies in moisture on either side of Hector's dividing line. It contains less moisture than some British coals. Mokau-Awakino pitch coal should really be classified as a hydrous coal.

Composition of New Zealand Coals

	Water.	Volatile matter.	Fixed Carbon.	Ash.	Sulphur.
Brown Coal (*a*):					
Average . . .	14·07	37·93	41·92	5·34	2·5
Extremes . . .	11·00	35·00	37·00	2·00	0·3
	20·00	50·00	51·00	13·00	5·0
Pitch Coal (*a*):					
Whangarei: Average .	7·45	41·13	46·42	5·00	
Extremes . . .	6·00	38·00	43·00	3·00	
	9·00	46·00	49·00	8·00	
W. Coast: Average .	7·61	38·29	46·61	7·47	
North Island: Extremes	4·80	30·00	40·00	0·50	
	9·20	39·00	60·00	12·00	
Bituminous Coal:					
Westport (*b*) . .	1·78	38·55	58·04	1·63	1·5 to 4·0
Greymouth (*c*) . .	2·35	35·35	59·26	3·04	0·29
Anthracitic Coal:					
Paparoa Range, Greymouth	0·74	15·69	79·52	4·05	0·48

* Analyses quoted: (*a*) by Park; (*b*) by Morgan and Bartrum; (*c*) by Morgan.


NEW ZEALAND
Whangarei Hbr.
Auckland
Waikato R.
Mokau R.
Hawke Bay
Wanganui R.
Golden Bay
Westport
Greymouth
Christchurch
Opihi R.
Shag Pt.
Dunedin
Invercargill
166
170
172
174
176
178
34
36
38
40
42
44
46

Brown Coal.—Half of the available coal of New Zealand is of this class. Usually it is soft and easily mined, but sometimes is extremely tough.[1]

Pitch Coal (Sub-bituminous).—This coal is bright, glossy and friable, and some, for instance Mokau river coal, is so deceptive in general appearance that it might be readily mistaken for anthracite. The Kawakawa coal, sometimes called glance coal, is frequently termed semi-bituminous, as in official returns.

Bituminous Coal.—The chief deposits of this coal are in the Westport and Greymouth districts, and in both are of excellent quality. Coal from the former district, though friable and making a large amount of slack, is, on account of its extraordinary purity and ready combustion, a very valuable coal.

Semi-Anthracitic Coal.—On the eastern slopes of the Paparoa Range, near Greymouth, coal of this character, of a high calorific value and occurring below the Brunner coal horizon, has been mined to some extent.

Classification of Coals according to Age

Since 1866, extensive field-work has thrown much light on the geological age of the various coal-basins, but even now unanimity on this subject has scarcely been reached. Nor is this surprising, considering the complexity of the geological problems. The following record may, however, be regarded as reasonably accurate, and is based on the lines followed by James Park [165]:

I.—*Kainozoic*

Miocene: Oamaru brown coal series	*N. Island.*—Taupiri - Huntly, Waipa - Hikurangi (Waikato basin); Mokau and Upper Wanganui.
	S. Island.—West Wanganui, Inangahua Valley (Nelson); Mt. Somers, Kakahu, Waihao (Canterbury); Ngapara, Waikouaiti, Green Island, Saddle Hill (Otago); Forest Hill, Nightcaps (Southland).

[1] In spite of the tendency of brown coal to crumble, a long-exposed natural section of Kaitangata-Taratu coal, 23 ft. thick, with 20·55 per cent. of moisture, examined by the writer, showed a solid, unfractured face and gave a normal analysis.

Upper Eocene : Waimangaroa bituminous coal series	*S. Island.*—Collingwood, Pakawau (Nelson); Mokihinui, Ngakawau, Denniston or Coalbrookdale at Waimangaroa (Westport); Grey River Valley, Paparoa Range (Greymouth).

II.—*Mesozoic*

Upper Cretaceous :	*N. Island.*—Kawakawa, Hikurangi, Ngunguru (N. Auckland).
Waipara series	*S. Island.*—Shag Point, Kaitangata (Otago); Malvern Hills (Canterbury).
Jurassic :	*S. Island.*—Waikawa, Catlins River (S.E. Otago); Hokonui Hills (Southland).

Coal Areas

The areas referred to in the following notes are taken in order from north to south:

1. *North Auckland* (*Upper Cretaceous*).—The coal-bearing measures in the peninsula to the north of Auckland occur in detached areas. Though small, they have contributed considerably to the coal production of the country, but the annual output does not now exceed 120,000 tons. The coal is generally known in New Zealand as glance, or pitch coal, but recent Mine Statements refer to it as semi-bituminous.

In the Kawakawa area the coal seam, practically exhausted in 1900, was 8 ft. 6 in. thick, thinning out in certain directions, and in Hikurangi the only known seam varies from 2 ft. to 11 ft. In the Kiripaka section of the Ngunguru field the seam is 16 ft. thick, and recent boring has proved extensive coal-bearing ground to the dip of the Ngunguru section of the field. Composition is: Water, 4 to 6 per cent.; Vol. matter, 36 to 48 per cent.; Fixed Carbon, 40 to 56 per cent.; Ash, 1 to 15 per cent.; Sulphur, 1 to 6 per cent.; Calories, 6,600 to 7,000.

2. *Waikato* (*Miocene*).—This important area lies in the basin of the Waikato river, and extends from Drury southward for 48 miles, and west to the sea, a distance varying from 20 to 25 miles. The Coal-Measures outcrop in the Waikato valley and dip westward. They also extend south and south-west to Raglan, Kawhia, Upper Waipa, Hikurangi, Awakino and Upper Mokau, where, however, they are still undeveloped.

The coal has been worked to a considerable extent at shallow

depths in the Waikato valley, and partly even beneath the river-bed and Lake Hakanoa, where the overlying strata or "cover" consists of incoherent pumice, sand and mud. Fortunately, this has been accomplished without serious mishap hitherto.

The coal is a hydrous brown coal, disintegrating on exposure, and gives the following divergent analyses:

After.	Water.	Vol. matter.	Fixed Carbon.	Ash.	Sulphur.
Park . . .	17·60	33·24	47·08	2·08	0·80 to 2·00
Morgan . .	12 to 15	41 to 46	36 to 44	2 to 3	under 0·50

5,400 to 6,100 Calories.

The output from this area, including a little from Mokau, is about 350,000 tons per annum.

3. *Mokau-Upper Wanganui* (*Miocene*).—This is the most extensive coal-field in New Zealand. It stretches from the Upper Mokau and Awakino to the sea, a distance of 35 miles, and from Upper Awakino southward to the Upper Wanganui, a distance of 40 miles. The general dip is southward. J. M. Bell states that there are several seams exposed on the Mokau river [162], and, according to Park, there is one seam, at least, varying in thickness from 4 to 16 ft. The coal at outcrops on the Mokau river examined by the writer was from 4 to 7 ft. thick, and crumbled rather freely on moderate exposure. Its composition is: Water, 11 to 14; Vol. matter, 38 to 43; Fixed Carbon, 38 to 40; Ash, 6·7 to 7·8; Sulphur, 1·8 to 2·7 per cent.; Calories, 5,900.

Going eastward, the coal of this field gradually changes in character from pitch to brown coal.

4. *Collingwood and West Wanganui* (*Eocene and Miocene*).—Park described this district in 1899 [166], and in the same year the writer examined the seams being worked at Collingwood. The following details are taken chiefly from Park's later descriptions [165]:

At Collingwood, on Golden Bay, six thin seams of bituminous coal occur in Eocene rocks (Waimangaroa Series). The second and third seams, 2 ft. 5 in. and 3 ft. thick respectively, produce excellent coal, but, on account of their thinness and recurring faults, mining operations are said to have ceased. An average

analysis is: Moisture, 2; Vol. matter, 36; F.C., 57; Ash, 5; Sulphur, 0·64 per cent.

These seams recur to the north between Pakawau stream and Cape Farewell. They are mostly thin, but one, about 7 ft. thick, has been worked. It contains rather more water, ash and sulphur than Collingwood coal.

The Coal-Measures dip at 20° from Collingwood to the N.W., and at W. Wanganui Inlet are overlaid conformably by the upper Coal-Measures (Oamaru Series).

The W. Wanganui coal-field has an unbroken stretch along the coast from the Inlet to Golden Ridge; and southward it extends in detached areas to Turimawiwi valley, a total distance of 18 miles.

At the Inlet there are outcrops of a 4-ft. seam of "pitch coal" dipping slightly seaward, and Park, in 1910, refers to an outcrop of coal 6 to 8 ft. thick. The analysis is:

Moisture.	Vol. matter.	F.C.	Ash.
4·8 to 8·6	37 to 39	45 to 50	4·2 to 4·8

Southward the coal merges into hydrous brown coal. Between Paturau and Golden Ridge one workable seam occurs. The analysis is:

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.
12·41	20·20	51·17	16·22	3·2

The coals of Collingwood and W. Wanganui may eventually be utilized locally.

5. *Buller–Mokihinui* (*Eocene*).—The bituminous coal supply of New Zealand is practically confined to the Buller–Mokihinui and Greymouth coal-fields, and, fortunately, the quality of the coal in each is excellent.

The Buller–Mokihinui coal-measures occupy a narrow belt of rugged country roughly parallel with the coast, stretching northward from the Buller river to a little north of the Mokihinui river, a distance of about 30 miles. The maximum width is 10 miles. The general dip, though far from uniform, is to the north-east from the slopes of Mount Rochfort (3,382 ft.) in the south to sea-level at Mokihinui.

The coal-bearing beds, once continuous, have, through faulting and erosion, been reduced to isolated and comparatively small areas; also, the thickness of the coal is subject to rapid variation, a diminution from 40 ft. to 4 ft. within a short distance having come within the writer's observation. Morgan and Bartrum, in their valuable monograph on this field [163], mention an increase in thickness from 2½ ft. to 53 ft. within a mile and a half in the Millerton area. These observers, after an exhaustive examination, estimate that out of 137 sq. miles covered by Coal-Measures only twelve have been definitely proved to contain workable coal; but they admit that this estimate may be possibly increased after further exploration.

Park applies the term Waimangaroa Series to these measures, after the creek of that name. The coal-bearing beds are correlated with the Brunner beds of the Greymouth field. (See Greymouth, p. 151.)

Faults are numerous and distortion of the strata is frequent. Two main faults occur, the Kongahu, or Lower Buller, fault and the Glasgow fault. The former, to the west, runs N.E.–S.W., close to and parallel with the coast; the latter, to the east, runs due south. They are 4 miles apart at Mokihinui and 17 miles opposite Mt. Rochfort. Both are due to uplifts of the strata to the east, and increase in extent of throw rapidly from north to south, till each, opposite Waimangaroa, probably exceeds 5,000 ft. Between these the Williams fault, smaller but similar in kind, begins south of Ngakawau, and runs parallel to and 5 miles distant from the Kongahau fault. These thus form a series of step faults rising to the east.

Practically all the workable coal lies in a belt 5 miles wide, immediately east of the Kongahu fault, erosion having removed the bulk of the coal further inland, while westward of the fault the Coal-Measures are hidden beneath the narrow coastal plain, and dip towards the ocean. Where more seams than one occur, they are probably splits of the same bed.

The coal horizon at Mt. Rochfort is underlaid by a great thickness of gravel conglomerate, which dies out northwards till the coal in the areas where worked lies within a short distance of the crystalline basement rocks. At Coalbrookdale of the Westport Coal Co., the writer was informed by the

manager that at one point in the workings the comb of an outcropping quartz reef was found protruding into the coal-seam.

The opinion generally held that this and the Greymouth coals are of drift origin is doubtless correct, the evidence here in favour of the "drift theory" being as strong as that in favour of the "growth-in-situ" theory in so many other coal-fields.

The average composition of this remarkably fine Tertiary coal is given on p. 144. In freedom from ash impurity it is almost unrivalled among coals.[1] But the percentage of sulphur is high.[2] The coal produces good, but light and highly porous coke in beehive ovens. The output from the Buller coal-field in 1918 was 580,796 tons (2,240 lb.).

From the method of mining adopted on account of the thickness of the seam and the physical nature of the coal, the loss of coal in mining is very great. The extremely limited reserves of this class of coal in New Zealand, and indeed of all coal in the country, would seem to call for an enquiry into the possibility of reducing this waste. Experience under possibly greater natural difficulties in the Ombilin mine, in Sumatra, where, in a 27-ft. seam, practically no coal is lost, might furnish valuable information on a subject of such importance to the Dominion.

6. *Greymouth* (*Eocene*).—Next to the Buller coal-field the Grey is the largest producing field of New Zealand. Roughly it extends from the Grey River valley northward to Ten Mile Creek, and from the sea eastward to Blackball Creek, comprising an area of 75 sq. miles in one block, largely water free. The Coal-Measures lap round the south end of the Paparoa Range, resting unconformably on older Mesozoic rocks. They have a general but variable W.S.W. dip from a height of over 5,000 ft. at Mount Davy and Blackball Peak to the coast, where

[1] The purity of some thick Tertiary coals is notable. For instance, this Buller coal, with a thickness up to 53 ft., has 1·63 per cent. Ash; Ombilin coal, Sumatra, with a thickness up to 27 ft., has 1½ to 2 per cent. Ash; Makum coal, Upper Assam, with a thickness up to 80 ft., has 2·03 per cent. Ash; Brunei coal, British North Borneo, with a thickness of 28 ft., has 1·58 per cent. Ash.

[2] This fact was evident in the atmosphere of the Albion Mine workings in the crushed coal of the Kongahu fault zone, where eyes and throat were painfully affected by the sulphurous air.

they are exposed from Seven Mile Creek to Ten Mile Creek. South of Seven Mile Creek to the mouth of the Grey River they are hidden beneath the Twelve Apostles Range.

Coal-Measures (after Morgan) [164/p. 51]

Main Divisions.	Subdivisions.	Estimated thickness.	Remarks.
Kaiata Mudstone		2,000 to 3,000 ft.	Contains one coal-seam locally workable.
Island Sandstone		500 ft. (max.)	Often calcareous.
Brunner Beds	(*a*) Coarse sandstones, grits and pebble beds	300 to 400 ft.	Horizon of Brunner, State Mine (No. 1), and Blackball coal-seams.
	(*b*) Pebble-beds and conglomerates	0 to 400 ft.	At Ten Mile Creek contain coal-seams.
Paparoa Beds	(*a*) Upper sandstones and shales	700 to 800 ft.	Contain one or two minor coal-seams, workable in places.
	(*b*) Middle sandstones, with minor shales	500 to 600 ft.	Contain many small coal-seams, some workable in places.
	(*c*) Lower sandstones and shales	700 to 800 ft.	Contain 3 to 6 workable seams.
	(*d*) Basal conglomerate, with minor sandstones	0 to 1,000 ft.	Lower layers very coarse.

The Brunner beds are the representative of Park's Waimangaora Series of the Buller–Mokihinui coal-field, but the important underlying Paparoa coal-bearing beds are entirely absent from the Buller field, and are, according to Morgan, so far as known, unrepresented in any other coal-bearing strata in New Zealand [164/p. 53].

Kaiata Mudstone.—A mile north of Seven Mile Creek, Kane's seam has been worked on a small scale for some years. The quality is indifferent, and boring at various places has disclosed no other coal of value in these beds.

Brunner Beds.—The difficulty of correlating the coal-seams of this district is great. The surface is rugged and often timber-clad, while the seams are much contorted, variable in thickness and dislocated by frequent faults. Morgan, who examined this field exhaustively in 1911, considers that in

these beds "at least five seams reach workable thickness in places, but not one, except possibly the Brunner seam, is known to extend over the whole field." Hence, in any one locality, two workable seams at most are found, frequently only one. The thickness may vary from 2 to 12 ft., and may rarely reach 20 ft.

The quality of the coal as a whole is excellent, but varied, as shown in the following analyses:

Mine.	Water.	Vol. matter.	F.C.	Ash.	S.	B.T.U.
State No. 1 .	8·36	41·52	48·70	1·42	(0·82)	12,857
Brunner . .	0·47	39·03	54·70	5·80	(2·31)	14,537
Blackball . .	3·52	48·66	40·67	1·15	(4·70)	13,574

The output from Greymouth has hitherto been almost entirely from the Brunner beds.

Paparoa Beds.—The Paparoa Coal-Measures outcrop on the crest and east and west slopes of Paparoa Range, and contain an upper and a lower series. The upper series (Moody's Creek seams) appear near Seven Mile Creek on the western slopes of the range. Outcrops of 5 or 6 seams show thicknesses ranging from 2 or 3 ft. to 7 or 8 ft. The individual seams vary greatly in thickness, and in many places contain dirt-bands. Their average analysis is: Moisture, 2·4; Vol. matter, 37·0; Fixed C., 57·0; Ash, 3·4; Sulphur, 0·4.

The lower series appear on the eastern side of the range, where the seams have been opened up by the Paparoa Coal-mining Co. The seams vary from 3 to 20 and even 25 ft. in thickness, and are semi-anthracitic. On the western side of the range the coal, worked by the State Coal-mine, reaches a thickness of 20 ft., and is bituminous.

An average analysis of these lower seams is:

	Moisture.	Vol. matter	F.C.	Ash.	Sulphur.	Calories.
Paparoa Mine .	0·60	16·66	77·59	5·15	0·305	8,285
State Coal-mine .	1·57	38·22	57·49	2·72	0·460	8,008

The Paparoa Beds contain about fourteen workable seams, many of which, however, become in places too thin to work, or have been denuded.

The output from the Grey coal-field in 1915 was 529,245 tons (2,240 lb.).

7. *Charleston–Brighton* (*Miocene*).—On this coastal district,

south of Westport, brown coal occurs, but is at present of purely local interest. Moderately air-dried samples contain from 16 to 21 per cent. of water and over 5 per cent. of sulphur. A few miles inland from Brighton outcrops of anthracitic coal in faulted country are found, as well as some bituminous coal.

8. *Inangahua* (*Tertiary*).—This basin extends from the Buller river southward to Reefton, and has an average width of 10 miles. It contains at least two seams of superior pitch coal, an upper seam from 2 ft. to 20 ft. thick, and a lower seam from 4 ft. to 18 ft. thick. The analysis of coal worked at Murray Creek is: Water, 7·68; Vol. matter, 36·72; Fixed C., 54·52; Ash, 1·08; Sulphur, 1·24 per cent.; but the coal varies in character, and is only used locally.

9. *Maruia-Matakitaka* (*Lower Tertiary*).—This basin lies to the east of the preceding, and occupies a belt 30 miles long and 2 miles wide from the Owen River to the Matakitaka. Upper and lower Coal-Measures are represented, the upper, or Oamaru, series having ten thin seams of brown coal, and the lower, or Waimangaroa, series having several seams of bituminous coal, ranging from 2 to 6 ft. in thickness. At Hampden two seams of bituminous coal, 3 ft. and 4 ft. thick, give the following analysis: Water, 1·2; Vol. matter, 38·8; Fixed C., 56·4; Ash, 3·6; Sulphur, 1·2 per cent.

In the Owen area, an outlier of the lower measures of the Maruia field lying south of the Buller River, there is a 6-ft. seam of similar bituminous coal.

10. *Malvern Hills* (*Upper Cretaceous*).—This coal-basin lies, and the coal-seams occur, in isolated areas from the Rakaia river northward to the Upper Waimakariri Valley at heights of from 1,000 ft. to 3,000 ft. above sea-level. The coal is ordinary brown coal, but, in patches of no great extent, has been devolatilized and altered to anthracite by intrusive sheets of basalt and dolerite. The strata have been considerably disturbed and tilted by these intrusions, and are also cut up by faults. The unaltered coal has from 20 to 28 per cent. moisture, 35 to 40 per cent. volatile matter, 30 to 40 per cent. fixed carbon, 3 to 12 per cent. ash, and from 1 to 3½ per cent. sulphur. In the altered coal, moisture and volatile matter may each be reduced to 2 per cent. A seam, 6 to 7 ft. thick,

has been worked at Homebush Mine, in South Malvern district, since 1873.

11. *Kakahu* (*Miocene*).—This is the principal undeveloped area of brown coal of southern Canterbury, and is situated in the Kakahu, a tributary of the Opihi River. Several seams are found, the thickest varying from 4 to 7 ft.

Analysis of Coal

Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.
22·00	35·50	38·25	4·25	2·24

Coal is found at many points in the hills west of the Canterbury Plains, beneath which it probably extends as a syncline to the sea, where, as quoted by Morgan [167], large pieces of brown coal have been obtained by trawling at several places from depths of 30 or 40 fathoms. Large fuel reserves may therefore exist.

12. *Shag Point* (*Upper Cretaceous*).—At the base of the Waipara series, beneath 300 ft. of compact sandstone, there are seven coal-seams, which are mostly thin. Three seams, varying from 4 ft. to 6 ft. in thickness, are worked at Allandale Colliery, the only producing mine. The coal is one of the best brown coals, and has: Water, 16·57; Vol. matter, 33·70; Fixed C., 43·15; Ash, 6·58; Sulphur, 2·10 to 4·20 per cent. Here, as at Green Island, small rounded quartz pebbles are occasionally found embedded in the coal.

13. *Green Island* (*Miocene*).—This fairly extensive field, just north of Dunedin, is supposed to extend southward beneath Dunedin and Otago Peninsula, and contains an upper seam 2 ft. to 8 ft. thick, and a lower seam 6 ft. to 20 ft. thick. The quality of the coal is rather inferior, and has: Water, 18·67; Vol. matter, 36·57; Fixed C., 40·84; Ash, 3·92; Sulphur, 2 to 2·4 per cent.

14. *Millon-Kaitangata* (*Upper Cretaceous*).—This important basin lies on the coast from 40 to 60 miles south-west of Dunedin. It has an area of 65 sq. miles, and contains several seams of brown coal individually fairly uniform in thickness, of which four, aggregating 38 ft. of coal, are workable. The strata are a good deal faulted. The chief mining is at the

Kaitangata end of the field, where at Kaitangata Colliery, the largest producer, two seams, 35 ft. and 18 ft. thick, and at Taratu a seam, from 14 to 20 ft. thick, are being worked. The composition of these coals varies considerably. Analysis No. 1 is given by Park as an average; analysis No. 2 was made for the writer in the Government Laboratory.

	Moisture.	Vol. matter.	F.C.	Ash.	Sulphur.
No. 1, Average .	15·42	38·24	44·17	2·17	2 to 3
No. 2, Taratu outcrop	20·55	36·75	38·25	4·45	—

The annual output from this field is about 170,000 tons.

15. *Nightcaps* (*Miocene*).—About 45 miles N.N.W. of Invercargill, at the base of the Takitimu Mountains, superior brown coal, resembling Waikato coals in the North Island, is found in a belt 20 miles long over an area of 27 sq. miles. Three seams, aggregating 36 ft. of good coal, are being mined. An average analysis is: Moisture, 15; Vol. matter, 33; Fixed C., 47; Ash, 5; Sulphur, about 0·5 per cent.

The small coal-field of Forest Hill lies some 20 miles north of Invercargill, and contains coal of fair quality in a seam from 9½ to 11½ ft. thick.

Orepuki Coal

Some 20 miles west of Riverton a small area contains ar irregular seam of rather shattered coal from 4 to 15 ft. thick The coal is similar, but inferior to Nightcaps coal.

Lignite

Lignite deposits of considerable extent in Central Otago and in Southland are found at the base of Upper Miocene or Older Pliocene beds, occupying the basins of former great inland lakes. There is seldom more than one workable seam, varying usually from 6 to 20 ft. in thickness. But at Alexandria the main seam is 28 ft., at Clyde 44 ft., and near Roxburgh a vertical seam is 100 ft. thick. The analysis is: Water, 23 to 33; Vol. matter, 43 to 50; F.C., 15 to 25; Ash 4 to 9 per cent.; Sulphur, well under 1 per cent. (P. G. Morgan). These lignites, though low in calorific value (3,750 to 4,500

calories), have proved in the treeless districts of Central Otago very useful in the gold-dredging and other industries.

In Southland, lignite, from 6 to 23 ft. thick, occurs from Gore to Mataura, Wyndham and Clifton.

Output of Coal in New Zealand

Long Tons.

Year.	Bituminous and Semi-Bituminous.	Brown Coal and Lignite.	Total.
1915 . .	1,267,940	940,684	2,208,624
1916 . .	1,422,074	835,061	2,257,135
1917 . .	1,247,989	820,430	2,068,419
1918 . .	1,122,308	820,942	2,034,250

Coal Reserves of New Zealand

Park [165/p. 288] has estimated the workable coals, exclusive of lignite and seams under 2 ft. thick, to be:

Bituminous coal . .	254,500,000	tons
Pitch coal . . .	306,500,000	,,
Brown coal . . .	520,000,000	,,
	1,082,100,000	,,

and that their probable life is 140 years.

P. G. Morgan [2/p. 86] (Geological Survey of New Zealand) estimates:

Actual Reserve, less coal extracted . .	1,001,000,000	met. tons.
Probable Reserve	2,385,000,000	,, ,,
Possible Reserve, various coals, small to large.		

The coals of New Zealand offer a peculiarly interesting field of study, particularly in relation to the effect of dynamic and other influences on the rate of dehydration and devolatilization of the coals. It is interesting to conjecture to what extent the marked differences in coals of the same horizon and even of the same seams to be found in the Dominion are due to original composition, to bio-chemical changes in the constituent matter, and to subsequent dynamo-chemical influences.

ADDENDA

In addition to occurrences already described, there are several on which little exploratory work has been carried out; amongst these the following may be mentioned:

Kenia

Carbonaceous material has been found at Mwele, south-west of Mombasa [168], and similar material has been reported to occur on the Uasingishu Plateau. Analyses made at the Imperial Institute gave: Mois., 13·05; Vol. Mat., 27·80; F.C., 43·08; Ash, 16·07; Cal., 44·19. Indications of coal have been also noted at Sumburu [169].

Tanganyika Territory

Karroo coal-beds occur on the Songwe and Kivira Rivers, on the north-west side of Lake Nyasa, at one place 11 metres of coal occurring in a total thickness of 20·7 metres. A sample from one seam, 4·9 metres thick, gave: C, 60·6; H, 3·0; O, 13·0; S., 0·25. Mois., 4·3, Ash, 18·5; Çoke, 78·7; Cal, 56·57. It is not improbable that coal will be found in the Karroo formation east of Lake Tanganyika [170].

Somaliland

Sub-bituminous coal from a place 53 miles east of Berbera and 30 miles south of Karam, examined at the Imperial Institute, gave: Mois., 13·01; Vol. Mat., 35·16; F.C., 39·78; Ash, 12·05, S., 0·64; Cal., 56·61. The coal burnt freely, but did not cake [171]

Trinidad

Coal has been found on the south coast between Oropuchy and Moruga. An analysis of the material, which occurs in a seam 4 to 5 ft. thick, made at the Imperial Institute, gave: Mois., 13·7; Vol. Mat., 32·9; F.C., 34·0; Ash, 19·4; S., 5·06; Cal., 43·78 Lignite may also occur in quantity in the districts of Chatham and Trois [172].

Jamaica

Lignite of poor quality occurs and is used locally for fuel to a limited extent. Samples from four places examined at the Imperial Institute showed: 16·5, 48·8, 60·3, and 70·7 per cent. of ash respectively.

Windward Islands

Blocks of anthracite are stated to be common in St. Andrew's parish, Grenada, but the mineral has not been found *in situ*. A sample examined at the Imperial Institute showed: Mois., 2·40; Vol. Mat., 4·35; F.C., 83·82; Ash, 9·43; S., 0·54; Cal., 72·72.

British Guiana

Lignite in from 8 to 10 ft. seams occurs near Yarum Creek, 40 miles south of Georgetown on the Demarara river. A sample analysed at the Imperial Institute contained: Mois., 25·32; Vol. Mat., 33·52; F.C., 22·70; Ash, 18·46; S., 5·26; Cal., 32·91.

APPENDIX

CALORIFIC POWER AND EVAPORATIVE POWER

THE calorific value or calorific power of a coal is the amount of heat given out by completely burning a unit weight of coal, and is measured by the number of corresponding units of weight of water raised one degree in temperature by this amount of heat.

When the centigrade unit of temperature is used, the unit quantity of heat is termed the Calorie, and when the Fahrenheit unit is used, it is termed the British Thermal Unit (B.T.U.). To convert calories into British Thermal Units we have to multiply by 1·8.

The evaporative power of a coal is the number of units of weight of water at boiling-point that can be converted into steam at the same temperature by burning one corresponding unit weight of the coal. It is obtained by dividing the latent heat of steam into the calorific value, thus:

$$\text{Evaporative power} = \frac{\text{calorific value in calories}}{537}$$
$$= \frac{\text{calorific value in B.T.U.}}{967}$$

To determine the calorific value, a known quantity of coal is burnt completely in a special calorimeter, and the heat given off is measured by the rise in temperature of a given quantity of water in the calorimeter. Details of different calorimeters and their methods of use are given in text-books.

As an illustration of the foregoing, if one unit weight of coal (*no matter what unit of weight be used*) on complete combustion raise the temperature of, say, 2,506 *similar* units of weight of water 3° C., then:

$$\text{Calorific value} = 2{,}506 \times 3$$
$$= 7{,}518 \text{ Calories}$$
$$= 7{,}518 \times 1{\cdot}8$$
$$= 13{,}532 \text{ B.T.U., and}$$
$$\text{Evaporative Power} = \frac{13{,}532}{967}$$
$$= 14$$

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